Joint XXIV International Grassland and XI International Rangeland Kenya 2021 Virtual Congress

CONGRESS PROCEEDINGS

VOLUME I

Theme:
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods
Disclaimer

All rights reserved. Reproduction and dissemination of material in this proceeding for training or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged.

Reproduction of material in this proceeding for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:

Director General
Kenya Agricultural and Livestock Research Organization
57811-00200
Nairobi, Kenya
Email.info@kalro.org
Cell: 0722 206986, 0722 206988, 0709 104000
© KALRO 2022

Compiled and Edited by:
Dr. Joseph G. Mureithi
Prof. Moses M. Nyangito
Dr. Jane W. Wamuongo
Prof. Jesse Njoka
Dr. Elkana M. Nyambati
Dr. David Miano
Dr. Samuel Mbuku
Dr. Michael Okoti
Ms. Florida Maritim

Assisted by:
Prof. Dana Kelly, President of International Continuing Committee of the International Rangeland Congress, and
Prof. Ray Smith, Chair of International Continuing Committee of the International Grassland Congress, and by
Jordyn Bush and Adrian Hofrom of the University of Kentucky.

Design and Layout:
Emma Nyaola
Stephen Odipo
Henry Wanyama
Richard Kedemi
Nathan Maweu
Primrose Nabwire

Photography:
Stephen Odipo
Dr Samuel Mbuku

Citation: KALRO 2022. Mureithi J.G., Nyangito M.M., Wamuongo J.W. Njoka J., Nyambati E.M., Miano D.,
Mbuku S., Okoti M., Maritim F. (eds.). Sustainable Use of Grassland and Rangeland Resources for Improved
Livelihoods. Proceedings of the Virtual Joint XXIV International Grassland and XI International Rangeland
Organization (KALRO) 2022.

PREFACE

The International Grassland and Rangeland Congresses promotes interchange of information on all aspects of rangeland and grassland ecosystem for the benefit of mankind, including sustained development, food production and the maintenance of biodiversity. Meeting every four years, the congresses provide forums for stakeholders – professionals and practitioners - to get together to share views on issues relevant to rangeland and grassland resources. Therefore, every one of these congress - International Grassland and Rangeland Congress - focuses on a major contemporary issue or sets of issues which, in the views of the Continuing Committees working with host country organizers, require attention. These may be new technologies or approaches, emerging challenges, seeking ways of addressing the associated challenges while harnessing the opportunities, controversial issues with implications for sustainable utilization of rangeland and grassland ecosystem that require rational conversation, or global trends which may have consequences for utilization of rangeland and Grassland.

The Joint 24th International Grassland Congress (IGC) and the 11th International Rangeland Congress (IRC), was held virtually and hosted by Kenya in October 25-29, 2021. The joint congress focused on examining utilization of rangeland and grassland resources for improved livelihoods delivered through seven carefully identified sub-themes with a balance between the people, social, policy and the more traditional topics. The hosting of the first-ever joint congress in Africa was significant, as this region offers diverse and unique tropical savannah ecosystems, which are home to some of the most economically important grasses in the world and mesmerizing wildlife. The momentous event highlighted high tech (including ICT) technologies and enabled the scientific community and practitioners to deliberate on various advances made in the field of grassland and rangeland science and management. The key thematic areas were grassland/ rangeland ecology; forage production and utilization; livestock production systems; wildlife, tourism and multi-facets of Rangeland/Grassland; drought management and climate change; pastoralism, social, gender and policy issues; and capacity building, institutions and innovations for sustainable development in Rangeland and Grassland.

The Congress was organized by the Government of Kenya through the Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MALFC), in conjunction with the Animal Production Society of Kenya (APSK) and the Kenya Agricultural and Livestock Research Organization (KALRO). The Congress was to be held in October 2020 but due to the global COVID-19 pandemic, it was rescheduled to October 2021 with the hope this situation will have improved. However, due to the persistence of pandemic globally, a decision was made to deliver a virtual congress.

The organizational arrangements for the joint IGC-IRC Kenya 2021 were coordinated by a National Organizing Committee (NOC), comprising of members from (MALFC, APSK, KALRO, University of Nairobi, International Livestock Research Institute (ILRI), International Centre for Tropical Agriculture (CIAT), Intergovernmental Authority on Development (IGAD), International Union on Conservation of Nature (IUCN) and the Kenya’s Ministry of Interior and Coordination of National Government and other stakeholders involved in the development and management of Grassland and Rangeland in Kenya. The NOC worked in consultation with the International Grassland Continuing Committee and International Rangeland Continuing Committee that usually manages the affairs of the IGC and IRC between different congresses.

The congress NOC Secretariat used an online platform to handle abstract and paper submissions and reviews as well as maintain efficient communications with authors and keynote speakers. The papers were subjected to a review process before they were accepted for presentation at the plenary or as posters. A virtual congress platform was used to host the congress. A total of seven invited plenary Keynotes, 173 papers were accepted for oral presentation and 217 as posters through the virtual platform. Sixteen virtual exhibitions were also displayed. The oral papers were presented in 6 concurrent sessions, comprising of 45 sessions each dealing with a particular aspect of Grassland and Rangeland. The total delegates who attended the congress online were 675 (35% female and 65% male) from 66 countries. The attendance was spread across 11 regions: (i) Africa (246), (ii) Europe (84), (ii) North
America (78), (iv) South America (45), (v) South Asia (39), (vi) Oceania (33), (vii) East Asia (30), (viii) Mediterranean (23), (ix) Northern Eurasia (16), (x) Middle East (14), and (xi) Central America and Caribbean (14). There were excellent online discussions and people followed the congress through social media platforms including You-Tube. Through the virtual platform, many new friendships were made, old ones strengthened/renewed, and collaborations born.

The representation was diverse and encouraging. We would like to express our gratitude to the sponsors, reviewers of abstracts and papers and technical partners of the joint congress. Special thanks are due to the government of the Republic of Kenya which was a major sponsor and host of the congress, presenters and authors of papers and posters, our colleagues on the NOC and subsidiary sub-committees, institutions, groups and individuals who assisted in one way or the other, and the esteemed congress participants.

After the Congress, the papers were then subjected to light technical reviews and language editing, thus ensuring that intellectual content remains that of the authors.

The proceeding contains the papers that were presented as oral presentations and posters. The document will be a good reference for use by scientists, policy makers and practitioners to promote the interchange of scientific and technical information on all aspects for the development of Grassland and Rangeland globally.

Harry Kimtai, CBS
Principal Secretary,
State Department for Livestock,
Ministry of Agriculture, Livestock, Fisheries and Cooperatives

&

The Chairman, National Organizing Committee (NOC) of the Joint International Rangeland and Grassland Congress
KEY MESSAGES/ OUTPUTS

1. The International Rangeland and Grassland virtual congress platform opened an excellent opportunity for budding scientists and practitioners, and established inclusivity paths. The platform offered more flexible participation options and new opportunities for early-career scientists to engage, network, form research collaborations, exchange cutting-edge ideas and results. The young scientists also had the chance to explore new fields with rangeland and grassland luminaries from across the world to sufficient scale without the need for travel, thereby significantly reducing associated cost and time. The formatting of online congress allowed a more effortless transfer of information, especially considering the ease of recording and accessing all of the information, questions and participants within the (concurrent) sessions. As a result, the problem of choosing between parallel presentation tracks is becoming non-existent.

2. Rangeland and Grassland are an essential part of the complex and diverse livestock production and biodiversity conservation systems necessary for sustainable human development and global climate regulation mechanisms. These ecosystems that constitute over 50% of earth drylands provide significant opportunities for investment in sustainable development goals whose vision is to create a better, fairer world by 2030. But some serious challenges and threats must be addressed. We must harvest the diversity that exists and engage more widely with all key stakeholders.

3. The Congress recognized the critical role of pastoralism as one of the most sustainable production systems worldwide that play a significant role in safeguarding ecosystem services and biodiversity in Rangeland. In addition, the unique biological and cultural diversity of Rangeland and Grassland ecosystems contributes to goods, services, and knowledge that benefit humans beyond the herding communities. However, the current data on grassland, forestry, agriculture and livestock are insufficient for informing policymaking on rangeland-based livestock systems. There is urgent need to populate sufficient data at scale to inform policy and investment options for the Rangeland and Grassland systems. Only enabling technologies, policies, investments, and institutions will ensure that Africa’s rangeland and grassland ecosystems transition to help, not to hurt.

4. There is need for a paradigm shift towards sustainable pastoralism and sustainable use, conservation, and restoration of Rangeland and Grassland. The concept of “sustainable land management” in a rangeland/grassland context should begin with establishing appropriate institutions and be accompanied by behavioural change. This recognizes that the integrity and sustainable use of land resources and water are inextricably linked to functional traditional, local and other institutions.

5. Improving the information base is high on the agenda of the ongoing initiative to designate 2026 as an International Year of Rangeland and Pastoralists (IYRP) to raise global awareness of the importance of Rangeland and pastoralists for livelihoods and healthy ecosystems. Countries worldwide are encouraged to put forward an Action Statement for the next decade to ensure a sustainable future for Rangeland/ Grassland and pastoralists. This will include launching actions by partners and partnerships at global, regional and national levels to change policies and increase development resources and political commitments.

6. To sustain the global network of experts working in rangeland and grassland ecosystems, the Kenya experts resolved to create the Rangeland and Grassland Association of Kenya. The new association is expected to follow up on the Congress deliberations and momentum created by the Joint 24th International Grassland and 11th International Rangeland Congress (IGC/IRC). The Rangeland and Grassland Association of Kenya will bring together researchers, professionals, practitioners and resource users to address the challenges facing Grassland and Rangeland in Kenya and the IGAD region. In addition, this body is to unify, stimulate and foster focus and interest on Grassland and Rangeland for their development to play the rightful role in national and regional economic development.
7. The international participants missed opportunity for a face-to-face interaction besides the huge dividends accrued from the virtual meeting. Technology, while incredibly useful, can often be bound to certain constraints and unforeseen circumstances which in-person events can more easily adapt to. In the same breadth, there was no opportunity during the virtual congress to take someone aside for a “hallway conversation.” There were often threads of a particular topic of interest that needed to be discussed further with presenters informally. This is one of the many benefits of in-person social interactions that are missing in the world right now. Additionally, Kenya could not sufficiently show case the very rich cultural and natural heritage.
ACKNOWLEDGEMENT

We express our gratitude on behalf of the Ministry of Agriculture Livestock Fisheries and Cooperatives to the Continuing Committee of the International Rangeland Congress and International Grassland Congress for the support and providing the guidelines that were used in the preparation and hosting of the Joint Congress in Kenya. The core of the planning for the Congress was undertaken by the members of the National Organizing Committee (NOC) and its subsidiary Sub-Committees drawn from several institutions and individuals involved in the management of rangeland and grassland ecosystem. The Kenya Agricultural and Livestock Research Organization (KALRO) provided the technical congress secretariat that coordinated all the activities of the congress on behalf of NOC. We therefore, recognize the efforts of these experts and to all those individuals in the country who contributed to the preparation and hosting of the virtual congress.

The preparation and hosting of the important congress could not have been successfully accomplished without the financial support of the Government of Kenya. The support from the Cabinet Secretary and Principal Secretaries at the Ministry of Agriculture Livestock Fisheries and Cooperatives was monumental. The Ministry looks forward to further engaging stakeholders and partners in developing the rangeland and grassland systems for the benefit of Kenyan people. Additionally, the congress was substantially sponsored and technically supported by several key institutions: USDA – Agricultural Research Service; USDA - Natural Resources Conservation Service; Kenya Agricultural and Livestock Research Organization (KALRO); CIAT (International Center for Tropical Agriculture); International Grassland Congress; International Rangeland Congress; Animal production society of Kenya (APSK); Colorado state university, Warner college of natural resources; Kenya Seed Company; Food and Agriculture Organization of the United Nations (FAO); International Livestock Research Institute (ILRI); The Intergovernmental Authority on Development (IGAD); University of Nairobi; The International Union for Conservation of Nature (IUCN); The African Wildlife Foundation; Kenya Tourist Board, Kenya Export Promotion and Branding Agency (KEPROBA) and other government departments and agencies. We sincerely thank you.

Special thanks are due to the authors and presenters of papers and posters, the 115 reviewers and individuals who assisted in one way or the other, and the esteemed conference participants. Your relentless effort resulted in the development of this important congress proceedings. It is our hope that the proceedings will provide useful reference material - to sufficient scale - for those interested in understanding the major trends and associated issues covered during the congress to re-engineer development of rangeland and grassland ecosystems.
OPENING SPEECHES

SPEECH BY THE HON. PETER G. MUNYA, CABINET SECRETARY, MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVE (KENYA) DURING THE OFFICIAL OPENING OF THE JOINT 24TH INTERNATIONAL GRASSLAND CONGRESS AND 11TH INTERNATIONAL RANGELAND CONGRESS, KENYA 2021

The Chairman, Continuing Committee of the International Grassland Congress
The President, Continuing Committee of the International Rangeland Congress
The Chief Administrative Secretaries, present
The Principal Secretaries, present
The Chairman, Animal Production Society of Kenya

Distinguished Participants

Distinguished Guests, Practitioners Pastoralists and farmers

Ladies and Gentlemen,

It gives me great pleasure to participate in this auspicious occasion of the opening of the Joint International Grasslands and Rangelands Congress, Kenya 2021. I am informed this is the 24th International Grassland Congress and the 11th International Grassland Congress. Although the two congresses have been held for many years, with International Grassland Congress having a history of 100 years, I am informed that this is the first such joint congress in Africa, and the first virtual congress for both IGC and IRC. I want to take this early opportunity to thank the IGC and IRC continuing committees for the decision to hold this first joint meeting in Africa, here in Nairobi, Kenya.

Ladies and Gentlemen

The theme of the conference is ‘Sustainable Use of Grassland/Rangeland Resources for Improved Livelihoods’. This theme is very appropriate at this time in the history of mankind when we have challenges ranging from climate change to Covid-19 pandemic.

I am informed that the Congress is organized under seven thematic areas of rangelands and grasslands research and development, with a good balance between the people, social, policy and more traditional topics. I am also informed that the congress will cover 40 sessions each dealing with a particular aspect of grasslands and rangelands. This is very high concentration of information that should definitely be useful in managing grasslands and rangelands going forward.

Ladies and Gentlemen

The importance of grasslands and rangelands to the economy of Kenya and indeed for the Horn of Africa cannot be over emphasized. In Kenya the rangelands cover over 83% of the land mass and are home to 70% of the livestock and 83% of the wildlife. Over 10 million people derive their livelihoods from the existing natural resource in these areas. Due to the importance of grasslands and Rangelands, my Ministry has developed the Range Management and Pastoralism Strategy 2021-2031. The Strategy provides deliberate direction towards the realization of sustainable development of the rangelands in...
Kenya, recognizing the need for climate change adaptation and mitigation for better livelihoods, which is part of Kenya’s obligation as a signatory to the United Nations Framework Convention on Climate Change. The strategy has clear objectives of reducing land degradation, restoring degraded areas, while increasing land productivity; sustainably exploring the existing natural resources, development and adoption of appropriate technologies; support enterprise development and marketing of products; and promotion of other sustainable livelihoods in the rangelands besides livestock production. This is also articulated through, the Kenya’s Vision 2030, the Presidential Big Four Agenda and the Agricultural Sector Growth and Transformation Strategy 2019-2029, which all identified agriculture as one of the key sectors to deliver the economic growth rate envisaged in our development plan.

Ladies and Gentlemen
My Ministry recognizes the role of agricultural research and understands that the success of the sector is attributable to agricultural research and development initiatives over the years. I am glad that the Joint International Grassland and Rangeland Congress brings together scientists, policy makers and practitioners to promote the interchange of scientific and technical information on all aspects of grasslands and rangelands: including ecology; forage production and utilization; livestock production systems; wildlife, tourism and multi-facets of grassland and rangeland; drought management and climate change in rangelands; pastoralism, social, gender and policy issues, and capacity, institutions and innovations for sustainable development. I hope this scientific and technical information will be used to improve the productivity of the grasslands and rangelands globally - including Kenya and the Horn of Africa.

Ladies and Gentlemen
Allow me to turn to climate change issues. The productivity of the grasslands and rangelands has been under threat in the recent decades due to various factors. These include climate change and variability especially frequent droughts, fires and floods; land degradation and loss of biodiversity. These have threatened the sustainability of rangeland resources and created economic and environmental challenges that need urgent attention to safeguard the well-being of the communities especially the pastoralists. Urgent measures and interventions are therefore required to protect the grasslands and rangelands resources and enhance their sustainable utilization.

Kenya and indeed the Horn of Africa countries are currently facing a major drought that is threatening the productive assets of the pastoralists, their livestock. I recently declared the current drought a national disaster to enable the country mobilize resources to protect the livelihoods of the people living mainly in the arid and semi-arid grasslands and rangelands of Kenya.

My Ministry recognizes the threat climate change poses to sustainable development and is actively integrating climate change information into national policies. In this regard, Kenya launched its National Climate Change Response Strategy in 2010. The focus of the strategy is to enable Kenya reduce vulnerability to climate change and to improve the country’s response to climate change.

Kenya is also a signatory to the UN Framework Convention on Climate Change and the Kyoto Protocol. Kenya signed and ratified the Paris Agreement and the country has been an active participant in the Conference of Parties. Kenya has also ratified the United Nation Convention to Combat Desertification which is the sole legally binding international agreement linking environment and development to sustainable land management.

While the United Nations Convention to Combat Desertification address the reduction of land degradation; enhanced land productivity; sustainable utilization of the natural resources; development, adoption of appropriate technologies; support enterprises development, marketing of products; and promotion of other sustainable livelihoods in the rangelands besides livestock production, the Kenyan Strategy and Action plan is our commitments towards halting and reversing land degradation, restoring degraded ecosystems and sustainably managing our land resources. The major focus of these national strategies and action plans is mainly addressing the grassland and rangeland ecosystems that constitute over 80% of Kenya’s landmass.
Ladies and Gentlemen

Kenya is committed to ending drought emergencies and my Ministry has developed the National Drought Management Strategy which aims to building the resilience of the communities living in the rangelands of Kenya. Through Ending Drought Emergency Strategy, my Ministry has set out a system that will help us respond to drought emergencies in good time to prevent human suffering and death and also to protect the productive assets of our livestock keepers. In this regard, my Ministry has set aside funds that can be mobilized quickly whenever we have a drought emergency. In addition to this, my Ministry has piloted and is now together with the private sector is implementing index based livestock insurance scheme to protect pastoralist livestock.

I am glad to note that the congress gives attention to climate change issues and has a theme on drought and climate change. I hope the papers presented under this theme will underscore the urgency for all of us to unite in addressing climate change issues globally.

Ladies and Gentlemen

I take this opportunity to thank the organizers for electing to hold this congress in Nairobi and also underscore the efforts put in to make sure the congress is successful considering the challenges caused by the Covid-19 global pandemic. I am informed that during normal times, the congress is attended by at least 1,200 delegates. It would have been my wish and pleasure to have you all physically in Kenya as you share your knowledge and experiences on matters grasslands and rangelands, and to appreciate Kenya’s landscape.

Although you are holding a virtual meeting due to the Covid-19 pandemic, I want to take this opportunity to welcome you all to Kenya. Whenever you can please come and enjoy our world class hospitality, wonderful and unique wildlife, and our cultures.

Lastly, I congratulate the organizers for organizing this great congress and putting together world class keynote speakers to address important issues that affect grasslands and rangelands globally.

It is now my pleasure to declare the Joint 24th International Grassland and 11th International Rangeland Congress 2021, officially open.

THANK YOU VERY MUCH AND GOD BLESS YOU.
OPENING REMARKS BY PROF. HAMADI BOGA, EBS, CGH, PRINCIPAL SECRETARY (PS), STATE DEPARTMENT FOR CROP DEVELOPMENT AND AGRICULTURAL RESEARCH, MINISTRY OF AGRICULTURE, LIVESTOCK FISHERIES AND COOPERATIVES, NAIROBI, KENYA

Chief Administrative Secretary, Ministry of Agriculture Livestock Fisheries and Cooperatives, State Department for Livestock, Lawrence Omuhaka

Principal Secretary, State Department for Livestock, Harry Kimtai

Director General, KALRO, Dr. Eliud Kireger

President, International Rangeland Congress, Prof. Dana Kelly

Chairperson, International Grassland Congress, Prof. Ray Smith

Ladies and Gentlemen

Agriculture is essential for sub-Saharan Africa’s growth and for achieving the sustainable development goals particularly ending hunger, achieving food security, improving nutrition and reducing poverty. The Agricultural Sector Transformation and Growth Strategy 2019 -2029 (ASTGS) addresses the challenges in the agricultural sector and recognizes that the sector can contribute significantly to the 10 percent annual economic growth that is envisaged under the economic pillar of Vision 2030. Presently, however, agricultural production is negatively affected by constraints and changing factors that include: unsustainable land and environment management practices. The Government of Kenya recognizes the important role agricultural technology development and application can play in transforming and modernizing agriculture. Adoption of agricultural technologies and innovations can lead to increased productivity and quality along agricultural value chains. The department particularly wants to associate with The International Rangeland Congress and Grassland Congress with an aim of:

• Bringing to the fore the role of public and private partnerships in improving grassland/ rangeland resources and their derived livelihoods, particularly for pastoral people; and

• Enhancing sustainability of Grassland and Rangeland against adverse climate change.

Our direct equivalence to the two objectives, the ministry is implementing Kenya Climate Smart Agriculture Project (KCSAP), which among other areas, supports collaborative research programs to develop technologies, innovations and management practices for climate smart crops, livestock, aquaculture, land, water, agro-forestry, sustainable bio-energy and socio-economic research. The objectives are in the three wins: increased productivity, incomes and reduced Green House Gases (GHG). Implementation of this project is multi-sectoral, bringing communities, county extension service and research along specific value chains, identified by counties as priority areas. Specific projects already supported under the project are: Pigeon-pea technologies, innovations, management practices for enhancing productivity, food and nutrition security of smallholder communities in Kenya; Digital Dairy – ICT advisory to realize the forage triple win Validate and promote grass based diets for low enteric methane emissions for finishing steers, Evaluating input and output market systems for CSA finger millet in various Counties in Kenya among others.
Ladies and Gentlemen

National Agricultural Research System (NARS) Policy 2012 was formulated for the sector and has been implemented since 2013. Other legal instruments for agricultural research include, Technology and Innovation Act 2013; the Kenya Agricultural and Livestock Research (KALR) Act 2013; as well as the Universities Act of 2012. The National Agricultural Research System Policy is under review and seeks to streamline, rationalize and put in place a system that is consultative, efficient and effective and one that takes into account economies of scale to not only use the current scientific, human and physical capacities but also position Kenya as a hub for agricultural research, innovations and knowledge base in the region.

Within these broad priorities there were two priority research programs, namely, conservation of resources, which includes national soil/water management, farming systems research in dry land areas, livestock systems in pastoral areas and the generation and application of improved technologies in major agricultural zones. The second one was on crop and livestock research. This included breeding of improved varieties of major crops and vegetables and breeds of livestock, animal nutrition and veterinary research in areas of epidemic diseases and parasites.

It is expected that the reform process prompted by the policy will be harmonized and mainstreamed into the transformational processes that are taking place in the fields of agricultural education, training and extension, as well as in other scientific fields for the realization of the Government’s Big Four agenda on 100% food and nutrition security, and the Agricultural Sector Transformation and Growth Strategy (ASTGS), 2019 - 2029.

Despite past and ongoing initiatives, the East Africa region lacks strong policies to support implementation of the necessary climate change adaptation strategies so far researched. Some of the existing policies and frameworks, such as the East African Community Climate Change Policy (EACCCP), are not yet felt at the grassroots.

Ladies and Gentlemen

Crop-livestock integration one of management strategies that contributes to nutrient cycling that leads to sustainable productions systems. Vast amounts of crop residues available after grain harvesting become an important source of livestock feed especially during the dry seasons, while manure from livestock form organic fertilizer for crop production. It is common to see these crop residues being transported to Grassland and even Rangeland for livestock feeding during drought. Manure is in turn transported from Grassland and Rangeland to improve soil fertility and structure in crop lands. This system when managed efficiently can contribute significantly to sustainable grassland and rangeland productivity. It is my hope and believe that during this joint Congress information sharing on crop-livestock integration shall be explored for overall Agricultural productivity and improved livelihood.

I wish to take this opportunity to wish all delegates fruitful deliberations and say, we look forward to your input into our research programs and policies that shall make global agriculture responsive to the theme: ‘Sustainable use of the Grassland and Rangeland for Improved Livelihoods’.

THANK YOU
Welcome to the Joint International Grassland & International Rangelands Congress, hosted by Kenya. This is the first time there has been a joint international Grassland & Rangeland Congress in Africa. So, this congress is a significant moment in the history for both our organisations (the International Rangelands Continuing Committee and the International Grasslands Continuing Committee).

Rangelands and grasslands are important to the world, as these regions cover about half of the earth’s land surface area. We have rangelands and grasslands across the world: in much of Africa, in the Arctic, Australasia, Central Asia and Mongolia, eastern and southern Asia, the Middle East, North America, South American, the Caribbean, and even in Europe.

The health of these landscapes are critical to the wellbeing of more than 500 million people, some of the most marginalised people’s of the world. Pastoralists and others who derive their livelihoods from rangelands are both users and stewards of the land. Their stewardship is critical for building resilient economies, achieving food and water security, and improving environmental conditions. In Africa, rangelands and grasslands occupy almost half of the continents inhabited surface, and are home to 40 per cent of continent’s population. These regions support an estimated 50 million pastoralists and up to 200 million agropastoralists. However, many forces threaten the productivity and ecological integrity of these lands and their caretakers.

Rangeland degradation world-wide is a significant issue. Misunderstanding of rangelands is widespread; a common conception is that these lands are wastelands with little value, which need to be repaired, improved, or developed. This problematic notion of rangelands informs policies which are implemented in rangeland regions in many countries. The lack of understanding about complexities and regional nuances in rangeland means that the pastoralists who live here, have ended up as some of most marginalised and disadvantaged people in the world.

One initiative that will help overcome this lack of understanding is the proposal for an International Year of Rangelands and Pastoralists (IYRP), which has been proposal by Mongolian Government. While economic, social and institutional issues of rangelands are beginning to be recognised in some parts of the world, rangelands and pastoralists are often not a major consideration in government policy around the world. The proposed International Year of Rangelands and Pastoralists is an opportunity to promote messages about the importance of pastoralists.

The United Nations decision about whether or not an IYRP will happen, is likely to occur later this year. Please use your networks to encourage the government in your countries to support the IYRP – not only the Departments of Agriculture, also Departments for the Environment, forests and range management, and Departments of Foreign Affairs. Many of you may have contacts in pastoralists organisations, scientific and research organisations – all of these organisations can write and support the IYRP.

I would like to call on people around the world to step up. We need individual, communities, organisations and governments to support an IYRP.

This Congress will also increase our understanding of rangelands and grasslands. It is appropriate that this Congress is in Kenya – rangelands and grasslands are particularly important here, comprising 80% of this beautiful country, and are home to about 10 million people. These regions support 70% of the national livestock population and 90% of the wildlife, which is key to the tourism industry. There is a strong history of scientific research.
The Kenyans are bringing us a very exciting Program! The theme of the Congress is “Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods”, which is particularly topical at the moment. Much of Kenya is currently facing drought as the short rains are late, on top of previous dry seasons. Other countries in East Africa are in a similar position, with a La Nina weather pattern causing low rainfall. Government policies and funding are needed to support pastoralists in the short term, and strategies are needed to improve livelihoods in the rangelands in the longer term.

One of the seven themes at this Congress focuses on “Drought management and climate change”. Other themes focus on livestock, forage production as well as social and institutional issues. At this congress, the combined “people” related themes have one the largest number of papers (with about 60 papers). Ecological aspects of rangelands and grasslands also feature strongly (with about 40 papers). The balance of disciplines represented in presentations has changed over the years. The focus is more interdisciplinary, with a wider scope of topics now than 10 years ago.

The presentations, panel sessions and videos provide insights from both scientist’s perspectives, and importantly, insights from pastoralist’s perspectives. I am delighted that we have pastoralists from rural Kenya talking in Plenary sessions. It is not common that pastoralists present their views at an international rangelands and grassland congress. We tend to hear more from scientists at these congresses, yet it is vital that we hear from the people who actually manage our rangelands and grasslands. Congratulations to the organising committees for bringing us these different perspectives about rangelands and grasslands.

This congress is all virtual, another first for both the IGC and IRC. We all certainly wish we were able to meet face-to-face. We appreciate the time zone challenges of the online format; and thank those of you who are getting up very early or staying up very late. One of the benefits is that this format does allow people from remote villages to join in, some of these people would not be able to attend an international congress in person.

Welcome to all of you, to people from all over the world. I hope that you enjoy the exchange of ideas and find something of particular interest to you in this excellent program!
**XXIV IGC Business Meeting Minutes – All Virtual Meeting**

October 27 2021 from 2:15 to 3:45pm in Kenya

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opening Comments</strong></td>
</tr>
<tr>
<td>• Dr Ray Smith thanked attendees at the IGC Business Meeting and acknowledged the tremendous efforts of the Kenyan National Organising committee in organising this congress.</td>
</tr>
<tr>
<td>• The congress in Kenya has been jointly organised between IGC and IRC. Circumstances dictate that the next two will be IGC only in USA in 2023 and in Europe probably in 2027 celebrating the 100th anniversary.</td>
</tr>
<tr>
<td><strong>IGC Continuing Committee Members</strong></td>
</tr>
<tr>
<td>• Ray Smith thanked members of the Continuing Committee (CC) for their contributions since the last Congress in India in 2015.</td>
</tr>
<tr>
<td>• We have suggested that the terms for current IGC CC members be extended until 2023 given that the IGC constitution requires members to be nominated from attendees at the Congress. This was not possible with the Virtual nature of this year’s congress (see resolution 6 below).</td>
</tr>
<tr>
<td>• There have been two changes necessitated by current CC members being unable to complete their term.</td>
</tr>
<tr>
<td>o Dr.agr.Iveta Gutmane, Latvia completing the term of Dr. Alexander Adamovich, Latvia.</td>
</tr>
<tr>
<td>o Dr. Christian Huyghe, France completing the term of Dr Jean-François Soussana, France.</td>
</tr>
<tr>
<td>• Appendix A shows all current IGC Continuing Committee members</td>
</tr>
<tr>
<td><strong>Review and Approval of Minutes</strong></td>
</tr>
<tr>
<td>• <strong>Motion</strong>: That the minutes from 2015 Congress are a true and accurate record</td>
</tr>
<tr>
<td>o Moved: D Woodfield / P Ballerstedt CARRIED</td>
</tr>
<tr>
<td><strong>Review of Resolutions from XXIII IGC</strong></td>
</tr>
<tr>
<td>• Dr Smith read out the actions that had been taken by the Continuing Committee in response to the resolutions from IGC XXIII in India in 2015.</td>
</tr>
<tr>
<td>• Appendix A lists the 2015 Resolutions and actions taken.</td>
</tr>
<tr>
<td><strong>Constitution Amendments</strong></td>
</tr>
<tr>
<td>• No Constitutional amendments were received in the period required leading up to the XXIV IGC congress.</td>
</tr>
<tr>
<td><strong>IGC History</strong></td>
</tr>
<tr>
<td>• A comprehensive update of the IGC history has been written by Dr Vivien Allen and Dr Roger Wilkins as the primary authors and additional with input from Co-authors Dr. Garry Lacefield and Dr. Ray Smith.</td>
</tr>
<tr>
<td>• This history is available via the IGC website under publications (pdf can be downloaded for free or hardcopy ordered for $26.75 plus shipping).</td>
</tr>
<tr>
<td><strong>IGC Proceedings</strong></td>
</tr>
<tr>
<td>• The majority of proceedings papers presented at the last 5 IGCs are now available via a link on the IGC website to the site UKnowledge. (This project has been funded primarily by the University of Kentucky library system for which we are very grateful. Supplemental funding from the Forage and Grassland Foundation (private foundation started from the profits of the XIV IGC in Lexington, KY).</td>
</tr>
</tbody>
</table>
The Proceedings site has an internal search function or one can use any search engine to find papers by using author’s name and keywords from one of their Proceedings papers. Once found papers can be read from the site or downloaded free. If this simple search does not work, then add International Grasslands to the search. A record of the number of downloads will also be provided for author’s vitae. The International Grasslands Congress recently obtained copyright permission from Wageningen Academic Publishers for the XX IGC in Ireland (2005) to be included in the searchable database, previously this Proceedings could only be purchased as a hard copy or e-book. To reach the main site go to internationalgrasslands.org under click on publications or google International Grassland Proceedings.

Announcement and Invitation to the XXV IGC Congress in Kentucky USA 14-19 May 2023
- An extensive video was played inviting all delegates to Kentucky in May 2023. The venue will be in Northern Kentucky and in the wider Cincinnati area.
- The last time the IGC was held in USA was in 1981. The meeting will be organised and hosted by the American Forage and Grassland Council.
- A call for papers has been developed and will be re-released following the conclusion of IGC XXIV.
- First announcement is already on the IGC website.
- The date for title/summary submissions is 1 June 2022.
- The Organising committee are also asking for potential thematic sessions by 1 April 2022.
- A series of proposed pre-congress and mid-congress tours were outlined.
- Members at the business meeting reinforced the need for low-cost hotel packages to be available for delegates given that USA is a high-cost region for many people.
- The Organizing Committee is raising funds specifically designated for delegate sponsorships.

100th IGC Congress 2027
- Dr Frank Ewert and Dr Jurgen Pickert proposed Leipzig as the venue for the 100th anniversary IGC in 2027.
- They outlined the range of German organisations in the Grassland and Forage Community that have expressed their support for this event and two Government ministries in Saxony and Brandenburg regions.
- Julius Kuehn Institute – Grassland Science focus - interested in supporting this congress
- Thunen Institute
- Venue proposed is very near the location of original 1927 International Grassland Congress.
- Potential dates and pre- and post-Congress tours were discussed.
- It will be important to ensure that we avoid conflicts with timing of the European Grassland Federation meetings.
- Other groups can still propose other venues for this Congress and a full bid must be submitted to the IGC Continuing Committee before a final venue is confirmed. At present, the Leipzig bid is the only serious contender. Besides Leipzig, only convention bureaus have expressed interest, but none are connected with a grassland organization.
### Resolutions from IGC XXIV

The IGC Resolutions Committee (Dr Derek Woodfield, Dr Fernando Ortega, Dr Ray Smith & Babo Fadlalla) presented the following resolutions to attendees.

#### Resolution 1
- The members of the XXIV IGC congratulate the Kenyan Organizing Committee for their perseverance in putting together an excellent Congress in the face of an unprecedented pandemic that caused its delay until 2021 and ultimately resulted in a move to a virtual congress. The congress plenary sessions were informative and the volunteer oral and poster presentations provided an excellent overview of grasslands around the world. *Carried: Unanimously*

#### Resolution 2
- We thank the sponsoring organizations for their financial and in-kind support of the XXIV IGC particularly given the global financial situation associated with Covid-19. Sponsorship is a critical component in minimising registration costs for delegates, therefore, we recommend that the IGC continuing committee appoint a sub-committee to assist the XXV IGC Local Organizing Committee in identifying the appropriate contacts for sponsorship. *Carried: Unanimously*

#### Resolution 3
- That the XXV IGC Organizing committee make every reasonable effort to enable participants from as many countries as possible to attend by keeping costs low (including a range of accommodations), providing delegate sponsorship, and make every effort to promote the Congress Internationally. *Carried: Unanimously*

#### Resolution 4
- That ten dollars USD per attendee earned during the XXV IGC Congress should be provided to the IGC Continuing Committee as start-up funds for the next congress and to support early career researchers attending the congress. *Carried: Unanimously*

#### Resolution 5
- The Continuing committee should commission a study on the Global future of grasslands and present this at the 100th anniversary of the IGC in 2027. The study would involve all relevant stakeholders. *Carried: Yes from 87% of those voting*

#### Resolution 6
- That the term of the current IGC Continuing Committee members be extended until the next in-person IGC Congress 14-19 May 2023 in the USA since our constitution requires that “new members shall be nominated from the participating delegates in attendance at the Congress”. Consultations with past IGC CC Chairs provided the recommendation that new members should be nominated from those physically attending a Congress. *Carried: Unanimously*

#### Resolution 7
- That the IGC fully support the International Year of Rangelands and Pastoralists initiative for 2026 including providing representatives to the IYRP Global and Regional Support Groups. *Carried: Unanimously*

#### Resolution 8
- That the incoming IGC Continuing Committee consider the need for updated Country Pasture Profiles and lobby FAO for resources to update and reinstate a full set of publicly available Country Pasture Profiles. If successful, IGC will:
  - Identify potential authors to build on the previous work;
  - Work with authors to develop suitable guidelines and specifications for this new series; and
  - Put together a business case for the publication of the Country Pasture Profiles as an e-book (the prior electronic versions could apparently not be cited as a scholarly work).

*Carried: Unanimously*

All resolutions were approved by the attendees with voting occurring through the video-conferencing platform. Approximately 113 delegates attended the business meeting. Concurrently the IRC held their business meeting with 118 in attendance.

#### Other business
- None

*Meeting closed 3.48pm EAT*
1. Appendix 1 – Current IGC Continuing Committee Members
   Appointed in 2015
   - Region III [South America] Dr. Fernando Ortega, Chile
   - Region VI [East Asia] Dr. Joung-Kyong Lee, South Korea
   - Region VII [Middle East] Dr. Hayatullah Esmati, Afghanistan
   - Region VIII [Mediterranean] Dr. Ates Serkan, Jordan
   - Region X [Northern Eurasia] Dr. Alexander Adamovich, Latvia – Term will be completed by Dr. agr. Iveta Gutmane, Latvia
   - Region XI [Africa] Dr. Babo Fadlala, Sudan
   - India Organizing Committee serves one term - Dr. P.K. Ghosh, India

   Appointed in 2013
   - Region I [Canada, USA] Dr. Ray Smith, USA – Chair CC
   - Region II [Central America] Dr. Fernando Ibarra Flores, Mexico
   - Region IV [South East Asia] Dr. P. K. Ghosh, India
   - Region V [Oceania] Dr. Derek Woodfield, New Zealand
   - Region IX [Europe] Dr. Jean-François Soussana, France – Term will be completed by Dr. Christian Huyghe, France

2. Appendix 2 – Response and Actions to Resolutions from XXIII IGC India

   Resolution 1 – The members of the XXIII IGC congratulate the Indian Organizing Committee for putting together an excellent congress and we also thank the sponsoring organizations for their financial and inkind support. The congress plenary sessions were informative and the volunteer oral and poster presentations provided an excellent overview of grasslands around the world. The Organizing Committee is especially commended for publishing “Grassland: A Global Resource Perspective”. This will be a foundation text on the world’s grassland resources for many years to come. Carried: Unanimously Thank-you again Dr. Ghosh for this very successful meeting

   Resolution 2 – The XXIV IGC Organizing committee make every reasonable effort to enable as many countries as possible to attend by keeping costs low (including a range of accommodations) and make every effort to promote the Congress Internationally. Carried: Unanimously This was an important factor in setting the low registration fee for Kenya when it was in-person and setting a low virtual Congress fee.

   Resolution 3 – Since sponsorship is a key component of keeping registration costs at a reasonable level, the IGC continuing committee should appoint a sub-committee to assist the local Organizing Committee in identifying the appropriate contacts for sponsorship. Carried: Unanimously We did not do a good job with this but neither did the IRC Continuing Committee. Jim O’Rourke, the IRC Secretary, obtained the majority of the sponsorship.

   Resolution 4 – The IGC continuing committee should appoint a sub-committee to assist the local Organizing Committee in assigning papers to the appropriate themes. Carried: Unanimously We assisted with this and thanks to all those committee members who were active reviewers.

   Resolution 5 – Ten dollars USD per attendee earned during the congress (starting IGC XXIV) should be provided to the IGC Continuing Committee to be startup funds for the next congress and to support early career researchers attending the congress. Carried: Unanimously This will be collected from Kenya. Ten dollars USD for IGC and ten dollars for IRC for every delegate. We did not use these funds for early career researchers since Jim sponsorship dollars were all designated for delegate sponsors and these funds were not all used.

   Resolution 6 – The Organizing Committee of the XXIV IGC should give strong consideration to incorporating a mid-congress grassland tour into the congress program and to design some of the pre- and post-congress tours to highlight African grassland agriculture.
Carried: Unanimously Extensive tours were planned for Kenya and we already have good pre and mid-Congress tours options planned for IGC 2023.

Resolution 7 – Continue the Early Career Researchers Forum that was started in Australia and insure that early career researchers are included as keynote speakers. Carried: Unanimously An early career research forum will not happen in Kenya, but one is planned for IGC 2023. We should commit to early career researchers for keynote speakers. An effort was made in this regard for Kenya.

Resolution 8 – Given the demonstrated benefits of the joint IGC IRC 2008 meeting in China and considering the worldwide decreasing number of researchers as well as funds available for research in grassland and rangeland, the members of the XXIII IGC recommend that future IGC Continuing Committees make every endeavor to conduct joint activities with the IRC in order to maximize synergies in knowledge, practice, and resources. Carried: Unanimously As you know, Kenya 2021 is a joint Congress. We have a very good working relationship with IRC and look forward to continued joint meetings in the future. We have been very supportive of the International Year of Rangeland and Pastoralists Initiative spearheaded by IRC. Looking forward, IGC has a Congress in the USA in 2023 and IRC has a Congress in Australia in 2025. Since 2027 is the 100th Anniversary of IGC it is not planned to be a joint Congress.

Resolution 9 – The Continuing committee should commission a study on the Global future of grasslands and present this at the XXIV IGC. The study would involve all relevant stakeholders. Carried: Unanimously This is a resolution that has not been followed up on, but may be one to consider going forward, especially with our 100th Anniversary approaching. IRC commissioned a similar study. Here is the link [https://www.unep.org/resources/report/case-benign-neglect-knowledge-gaps-about-sustainability-pastoralism-and-rangelands](https://www.unep.org/resources/report/case-benign-neglect-knowledge-gaps-about-sustainability-pastoralism-and-rangelands)

Resolution 10 – In order to move the IGC Conference Proceedings to a higher scientific level, the Continuing Committee should pursue having the proceedings approved by Thompson Reuters to be listed in the Conference Proceedings Citation Index and be designated with an ISBN number. Carried: Unanimously I have been advised by our librarian that ISBN numbers are only for books and not Proceedings, but we have made great progress on our initiative to have all IGC Proceedings online and completely searchable. This project is in collaboration with the University of Kentucky library. A simple google search with appropriate keywords will now find individual Proceedings papers from the last 4-5 Congresses. We have just obtained permission from the publisher of IGC 2005 in Ireland to make these papers available for free on this website. Previously, only the hard copy or ebook of the Proceedings could be purchased. Authors can also obtain data on the number of downloads for their papers. We are planning to go back to 1927. We may limit the papers from the first two Congresses since we likely want to translate these from their original language of German.
Continuing Committee and Business Meeting Minutes

XI International Rangeland Congress Kenya – held as a Worldwide Virtual Congress

Sunday October 25 – Friday, October 29, 2021

1) One Continuing Committee Meeting was held on Sunday, October 25 and one meeting on Friday, October 29 Congress. Delegates were not invited to first meeting October 25th and did not attend. Congress delegates were invited to the second meeting on October 29th; attendance is recorded in Minutes of this meeting.

2) Traditionally two Business Meetings have been held, one on Sunday or Monday in which the Resolutions Committee and the Nominations Committee are introduced to the entire delegation in order for delegates to contact these people to submit resolutions and nominations, which then get voted on in the second Business Meeting traditionally held on Friday. At this Congress only one Business Meeting was scheduled, that on Wednesday, October 27, 2021. This did not give delegates the opportunity to submit resolutions or nominations during the week of the congress and resulted in a second Business Meeting held on Friday, October 29, 2021.

3) Opening and Welcome

OPENING REMARKS IRC BUSINESS MEETING

Wednesday 27 October 2021, by President Dana Kelly

“The aim of the International Rangeland Congress is to promote the interchange of scientific and technical information on all aspects of rangelands: research, planning, development, management, extension, education and training” (https://rangelandcongress.org 2021 p.1). To achieve this aim, the key activity to date for Continuing Committee (C.C.) members is to help organise an International Rangeland Congress (IRC), normally held every 3-5 years.

Organising an International Congress

We have excellent Congress Planning Guidelines, which go into detail about the various committees that need to be formed, exactly what those committees need to do and, most importantly, by when. These guidelines are on the IRC web-site (https://rangelandcongress.org Future Congresses tab) and are updated after every Congress. This time, the Guidelines will need considerable up-dating because this first Congress to be in a virtual format.

Organising an international congress that normally attracts between 500 to 1000 delegates (and over 1,500 in China) with several concurrent streams, is much more time consuming than most people realise. This is especially true if the country or organisation hosting the congress has not run many or any conferences of this size and scope. Surprisingly for many, organising papers and publications is the easiest part, even though it is perhaps the most visible and important part of the congress. Scientists organising scientifically-focused tours, negotiating contracts with hotels, coordinating bus timetable to pick everyone up from hotels amongst traffic jams — these are tasks that do not come naturally.

The Continuing Committee

The current C.C. has highlighted various other activities and actions that the C.C. could be involved with. These ideas have evolved from various chats over the past few years and culminated in an excellent discussion at our Sunday C.C. meeting. One of these activities is of course, the International Year of Rangelands and Pastoralists (IYRP).
I think it is time in the evolution of the IRC C.C. to consider the role of the committee and the roles of the various C.C. members. Up until now, too much responsibility for helping with the up-coming Congress has left to the IRC Secretariat and the President, and this is not sustainable. As member of the C.C. for 5 years before I become President, I must admit I did not feel very engaged and had little to do. Our discussions about the possible future roles for the C.C. have been developed into Resolutions.

I would like to take this opportunity to thank the Resolutions Sub-Committee for the sterling job they have done in taking our rambling discussions and developed these into some coherent and concise resolutions. These are quite open and really leave the job of refining what happens next to the new C.C.. As the retiring past President, I have an ex-officio position on the new C.C. so I’m around to continue these discussions with you. I would be glad to do so. While I had lots of ideas about how the C.C. could develop, I ended up too busy with the Kenyan Congress organisation to do anything else.

**Indigenous and Traditional peoples**

One thing I was involved with was how the Congress could better in terms of sharing the perspectives of Indigenous and Traditional Knowledge holders. While this is a passion of mine, this desire to hear more from Indigenous peoples has been reflected in IRC Resolutions for some time. The first significant mention was in a resolution at the Argentinian Congress in Rosario in 2011. Resolution 3 was about the “Recognition, support and participations of Indigenous and traditional pastoral peoples”.

My Kenyan colleagues and I had many discussions about how Indigenous people could be more involved and how to get Indigenous peoples from around the world to participate in the Congress in Kenya. An Indigenous Traditional Knowledge Forum was planned which planned to:

- bring people from Indigenous Communities around the world and take them to rural areas where they were to be hosted by several Kenyan communities. Several were involved in discussions regarding their desire to be hosts, their challenges and costs.
- bring visitors and locals back to Nairobi to spend time together to discuss their experiences.
- hold a Forum to hear from Indigenous peoples about their land management techniques, their challenges and successes, what issues they had in common as well as the differences.

Not everything that we initiated eventuated, due to chaos of Covid-19. The risks were high in bringing potentially vulnerable elders to Kenyan rural communities where vaccination rates were low and medical facilities are limited. Even though various options to minimise risks were considered, advertising around the world was not undertaken because of the uncertainties. Nonetheless, various actions were started. What did happen was that we:

- Reached out to communities around the world, making contacts.
- Initiated a film documentary about the role Indigenous Traditional Knowledge in Africa, especially in the IGAD countries in East Africa
- Formed an ITK Committee, which will continue after the Kenyan Congress committees close.
- Developed a plan for a Webinar series, which will hopefully run from 2021 until 2026, the proposed year for IYRP.

Interest in ITK is growing internationally, and we are starting to see greater awareness of the value of ITK. In Australia, interest is developing in how Australian Indigenous or Aboriginal culture may provide insights into how to manage increasing climatic variability. These insights could be in terms of land management e.g. cultural fire management; and also, in terms of governance arrangements and how to make decisions that embrace uncertainty and support resilient communities.
Next on the IRC Business Meeting Agenda

We shall now discuss the Resolutions that have been developed; as I said these indicate some possible future directions for the IRC C.C.. It is my view is that several sub-committees may be needed to help implement any new activities. I shall now hand over to James Bennett from the Resolutions sub-committee.

4) Update on IRC Secretariat

INTERNATIONAL RANGELAND CONGRESS SECRETARIAT REPORT

Submitted by James T. O’Rourke

For Period July 2016 to October 2021

1. IRC website domain name was renewed on 10/2016 ($60.95) and 9/2021 ($14.95).

2. IRC mailing list ability renewed annually with Linksky. Current charge on 5/2021 was $83.40 annually.

3. Jerome Vogel has provided a tremendous amount of support with IRC mailings at very little cost. Last payment to Jerome was for $700 on 7/ 2016.

4. Maintain MOU with Society for Range Management annually which allows IRC a complementary booth in the Trade Show at SRM Annual Meetings. Shipping charges in two cases for IRC banner to be in place.

5. A fee of $60 was paid for typing of the IRC History, edited by Jim O’Rourke, and will be included in the Kenya Proceedings.

6. IRC office is maintained at Chadron State College Rangeland Complex where computer, photocopy, FAX and telephone services are provided to IRC at no cost. IRC Archive of all past congresses is held here. Frequent requests for copies of papers in past proceedings are received at which time photocopies are made and emailed to the person requesting these reprints.

7. Emails checked daily (or weekly during summer season). Volume is huge.


9. Annual submission of IRC Profile to Sam.gov, which is necessary to receive grants/sponsorships from U.S. government agencies.

10. Password for Grants.gov renewed every 60 days, which is also necessary to receive grants/sponsorships from U.S. government agencies.

11. Sponsorships from U.S. government agencies must be made to a U.S. entity. Thus the IRS 501c3 status (tax exempt). U.S. sponsorships made up 95% of sponsorships for the Kenya Congress. When these sponsorships are received they are wired to the Host Country. In the case of Kenya some of these funds were retained in the U.S. to make dollar payments to IRC and IGC personnel who were traveling to Kenya to provide support in order to make payment easier and avoid wiring fee charges. IRC President made 3 trips, IGC Chair made 2 trips paid by sponsorships and at least two more at his expenses, and IRC Secretariat 2 trips.

12. IRC made a loan of $20,000 to Kenya Organizing Committee. This has been repaid by holding back that amount from sponsorships received into the IRC bank account. The loan IGC made of $10,000 to the Kenya Organizing committee was repaid in the same fashion.
13. The IRC bank account has been used for IYRP efforts with sponsorships received for IYRP and payments made for IYRP expenses keep separately.


15. See the separate IRC Financial Report.

FINANCIAL REPORT TO IRC CC

October 13, 2021

Covering period from January 1, 2015 to October 14, 2021

Submitted by James T. O’Rourke, Secretariat

EXPENSES:

1. Website $75.80
2. Mailing List $487.80
3. Jerome Vogel $700.00
4. Advertising $106.00
5. IRS (for 501c3 status) $410.42
6. Tax Preparation $1220.00
7. Bank Charges $20.00
8. Typing $60.00

TOTAL EXPENSES: $3080.02

REVENUE:

1. Interest – -$261.31

2. Canada Profits - $19,962.50 – Of this amount $5290 was for the $10 per delegate attending fee due to IRC. The remaining ($14,672.50) was a sponsorship from Canada for the Kenya Congress. This $14,672.50 has been used for travel by IGC and IRC personnel to and from Kenya to assist in planning preparations.

Additional Revenue and Expenses:

1. IGC and IRC travel to and from Kenya has totaled $25,488.38. With $14,672.50 from Canada Profits, $2455.00 from ICARDA and $3000.00 from CSU used for this item an additional $5360.88 will be held back from sponsorships to Kenya to offset these expenses.

2. IRC has loaned Kenya $20,000.00. This will be due back to IRC.

3. Items 1 and 2 immediately above, a total of $25,360.88, will be collected from Kenya when all sponsorship funds arrive in the IRC account, with any remaining returned (wired) to Kenya.

4. The IRC bank account has been used to assist the IYRP effort. $5500.00 has been received in sponsorships to support the IYRP. $3677.80 has been expended. Thus $1822.20 remains in the IRC account for use by IYRP.
Bank Balance August 1, 2017 immediately before Canada final payment to IRC $37,651.62

Bank Balance September 21, 2021 $48,257.94

Less amount held for IYRP $1,822.20

Less amount in bank from sponsorships to be used to repay IRC/return to Kenya $30,000.00

Temporary Bank Balance pending repayment and Kenya $10 per delegate fee $16,435.74

With repayment of $25,360.88 in 3. above $41,796.62

With payment of $10 delegate fee from Kenya (registration figures yet to be seen) ?

SPONSORSHIPS RECEIVED FOR THE KENYA IGC/IRC:

1. Canada Organizing Committee 2016 $14,672.50
2. Agricultural Research Service (ARS) of USDA $60,000.00
3. Natural Resources Conservation Service (NRCS) of USDA $10,000.00
4. Colorado State University $11,500.00
5. ICARDA $2455.00
6. FAO on behalf of CIRAD France $5,000.00

5. Review of Resolutions passed at 10th IRC Saskatoon, Saskatchewan Canada 2016

Resolutions Passed at the 10th International Rangeland Congress Saskatoon, Saskatchewan, Canada 2016

1. INTERNATIONAL YEAR OF RANGELANDS AND PASTORALISTS
   The delegates from the member countries of the International Rangelands Congress 2016, support a United Nations designation of an International Year of Rangelands and Pastoralists in the Year 2021.

2. GENDER & INDIGENOUS
   That future IRC Congress Organising Committees provides a forum for sharing the experiences of all genders, youth and indigenous peoples, so that their perspectives can be better integrated into science and policy regarding rangeland management.

3. THANK YOU TO CANADA
   The delegates and the Continuing Committee of the IRC thanks the organisers of the IRC Canada Congress for an excellent congress, especially the structure of congress sessions, the program and superb organisation, in a very short space of time.

4. MULTI-FUNCTIONALITY
   Future International Rangeland Congresses strive to highlight pastoralism as a multifunctional activity, with sessions linking production, environmental, social, cultural and institutional issues towards local development perspectives.

5. JOINT MEETINGS
   The IRC Continuing Committee explore opportunities for joint meetings with allied groups (such as ecology, conservation, economics, social development, wildlife, livestock and grassland groups) to address selected emerging regional/global management issues in rangelands.
6. REPRESENTATION ON CONTINUING COMMITTEE
The IRC strive for equal representation of men and women, and substantial representation from the global south, on the Continuing Committee.

6. New Resolutions passed at the 11th International Congress, Oct, 2021
Virtual and Mombasa, Kenya

The Resolutions Committee was co-chaired by James Bennett and Robin Reid and included David Phelps, Elisabeth Huber-Sannwald and Tony Palmer. Eight resolutions had been received prior to the Business Meeting on Wednesday as a result of communications with delegates prior to the congress. These resolutions were reviewed by the Resolutions Committee and modifications made in consultation with the person/groups submitting the resolutions. Only one of these resolutions received suggested amendments during the Business meeting on Wednesday resulting in that resolution being voted upon during the Friday Business Meeting. The approved resolutions, as voted upon by the full delegation include:

Resolution 1: Thank you to the Kenyan Organising Committee
The continuing committee extends its gratitude to the Kenyan Organising Committee for all its hard work in pulling together the International Rangeland Congress 2021, under difficult circumstances.

Resolution 2: Congratulations to Australia
The continuing committee congratulates Australia on the award of the International Rangeland Congress 2025.

Resolution 3: Actively Work with IYRP (International Year of Rangelands and Pastoralists) (IYRP Resolution 1)
Individual Continuing Committee (CC) members of the International Rangeland Congress (IRC) will be responsible for working with other IRC delegates and the International Year of Rangeland and Pastoralists (IYRP) Global and Regional Support Groups to gain country-level commitments to support the IYRP 2026 initiative, through letters and other acknowledgements submitted to the Mongolian Government in reference to their IYRP 2026 proposal to the United Nations, until such time as the UN General Assembly designates the International Year.

Resolution 4: Mobilize Support in Countries for IYRP (International Year of Rangelands and Pastoralists) (IYRP Resolution 2)
Individual CC members of the International Rangeland Congress will be responsible for mobilizing scientists and rangeland practitioners in the countries and regions that they represent, to support and work with the Regional IYRP Support Groups in developing IYRP Action Plans concerning the activities that will be conducted prior to and during the Year. These activities will coincide with the 12 monthly themes developed by the International Support Group (ISG) of the IYRP and will be discussed at the Society for Range Management Conference in February 2022. The IYRP Action Plans should be finalized before the end of 2022, and implementation commenced in January 2023, unless otherwise decided by the Global Coordinating Group of the ISG.

Resolution 5: Establish IYRP (International Year of Rangelands and Pastoralists) Sub-Committee of the International Rangeland Congress Continuing Committee (IYRP Resolution 3)
The CC of the IRC will establish an IYRP Sub-Committee that will prepare a report identifying priority research and comparable methodologies needed to address the knowledge gap findings, including those of the Gap Analysis conducted by UNEP in 2018, by October 2022 as an input to the IYRP Action Plans. This Sub-Committee will work with the Regional IYRP Support Groups including International Agencies, amongst them UNEP, FAO, ILRI, and regularly report on progress to both the CC of the IRC and the Global Coordinating Group of the ISG. The Sub-Committee will report on its achievements and findings to the IRC in 2025, including implementation of these three resolutions.
**Resolution 6: Establish Kenya IYRP (International Year of Rangelands and Pastoralists) Committee**

The Kenya International Rangeland Congress Organising Committee will work with the rangeland counties in Kenya to establish - in liaison with the Kenyan ministries of agriculture, livestock and fisheries -- a joint Kenya IYRP Committee responsible for coordinating regional and country-level commitments in support of the International Year of Rangelands and Pastoralism (IYRP) 2026 initiative. This committee will also encourage members of IGAD (Intergovernmental Authority on Development, covering the countries in the Horn of Africa) to participate in the IYRP. This will include:

- Developing action plans each year until the IYRP is launched
- Identifying and supporting research priorities that support the goals of the IYRP

**Resolution 7: Support international liaison for the International Rangeland Congress 2025 and beyond**

The International Rangeland Congress (IRC) Continuing Committee will establish effective international liaison in support of congress attendance in conjunction with future host nation organising committees, in order to:

1. Identify historically under-represented countries at IRC and how more effective linkages might be established, e.g. with in-country organisations, to facilitate closer liaison with IRC.

2. Identify potential constraints to delegate attendance at IRC from these, and other countries, and how these might be addressed.

3. Actively build the capacity of under-represented countries to host future congresses.

**Resolution 8: Explore Opportunities for Joint Congresses with Allied Groups**

The International Rangeland Congress Continuing Committee will explore opportunities for joint meetings with allied groups (such as ecology, conservation, economics, social development, wildlife, livestock and grassland groups) to address selected emerging regional/global management issues in rangelands.

**Resolution 9: Extend International Rangeland Congress Procedures to Include Virtual Congresses**

In light of the current pandemic it is proposed that the IRC continuing committee revise existing Congress Guideline Procedures to include handling a virtual congress.

**Resolution 10: Encourage and Report on Regional Activities**

A strategic planning meeting of Continuing Committee (CC) members, is established after each congress to clearly identify what the roles of CC members will be for the period to the next congress. Indicative roles and activities to involve but not be limited to:

i. Fostering communication among region members;

ii. Promoting and encouraging the mission of the International Rangeland Congress amongst member countries;

iii. Supporting IYRP (International Year of Rangelands and Pastoralists), participating in gap analysis of rangelands and pastoralism.

That these activities are then reported on at a meeting of CC members held every 12 months.

**Resolution 11: International Rangeland Congress Continuing Committee and Organizing Committee to Establish Diversity Sub-committees**

The International Rangeland Congress (IRC) Continuing (CC) and Organizing Committees (OC) will:

- Establish Sub-Committees on Diversity, Equity and Inclusion to advise on all IRC CC and OC activities, including recruiting and retaining diverse leadership and membership, conference
program development and structure, keynote and session speakers and panels, scholarship awards, field trips and other activities.

- Develop a Diversity, Equity and Inclusion statement and implementation plan to guide these decisions (see examples of such a statement by the US Society of Range Management here).

**Resolution 12: Incorporate Indigenous Leadership and Participation**

The International Rangeland Congress (IRC) Organizing Committees will:

- Incorporate the expressed goals, participation and leadership of Indigenous Peoples of the hosting countries in all aspects of each IRC meeting.

- Apply this to leadership and membership, conference program development and structure, keynote and session speakers and panels, scholarship awards, field trips and other activities of the meeting.

- Form an IYRP (International Year of Rangelands and Pastoralists) sub-committee of the IRC Continuing Committee (CC) for this purpose and/or

- Include this role within any other relevant committees of the IRC CC.

This resolution assumes that the next IRC will be held in 2025 as currently planned, and that the IYRP will be approved for 2026.

**Nominations for New IRC Continuing Committee Members**

CC members were encouraged to seek at least two nominations per region. Nominations had been made by CC members for persons to replace those going off the CC at this congress. Those nominations were reviewed at the CC Meeting on Sunday and presented to the full delegation at the Wednesday Business Meeting. Only one region had more than one nomination with the voting for that region on Wednesday resulting in a tie vote. One of these nominees subsequently withdrew his nomination. Following the Wednesday Business Meeting one other nomination came forward from another region. It became obvious that delegates had not had sufficient notice and time to submit nominations and therefore a second Business Meeting was scheduled for Friday with notice sent to all delegates to submit nominations as they wished. By the time of the Friday Business Meeting only this one region had received an additional nomination. On Friday, all nominations were voted upon to insure that delegates were comfortable with the nominations even if only one nomination had been received. Outgoing, Continuing and Newly Elected member are:

<table>
<thead>
<tr>
<th>Region</th>
<th>Outgoing member 2011-2021</th>
<th>Continuing member 2016-2025</th>
<th>Nominations 2021-2029</th>
<th>New member 2021-2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia/Oceania</td>
<td>Dana Kelly</td>
<td>David Phelps (Australia)</td>
<td>Nicole Spiegel (Australia)</td>
<td>Nicole Spiegel</td>
</tr>
<tr>
<td>Africa: Southern Africa, Sub-Saharan Africa</td>
<td>Anthony R Palmer</td>
<td>George Azenga Keya (Kenya)</td>
<td>Ighsaan Samuels (South Africa)</td>
<td></td>
</tr>
<tr>
<td>Africa: Northern Africa and Middle East</td>
<td>Mounir Louhaichi</td>
<td>Mohamed Tarhouni (Tunisia)</td>
<td>Nahid Naghizahed (Iran)</td>
<td>Nahid Naghizahed</td>
</tr>
<tr>
<td>Asia: Central Asia and Mongolia</td>
<td>Ayurzana Enkh-Amgalan</td>
<td>Dildova Aralova (Uzbekistan)</td>
<td>Tungalag Ulambayar (Mongolia)</td>
<td>Tungalag Ulambayar</td>
</tr>
<tr>
<td>Asia: China and East Asia</td>
<td>Fujiang Hou</td>
<td>Guodong HAN (China)</td>
<td>Yongfei Ba (China)</td>
<td>Yongfei Ba</td>
</tr>
<tr>
<td>America: North and Mexico</td>
<td>Elisabeth Huber-Sammwald</td>
<td>Robin Reid (USA)</td>
<td>Luis Ortega Reyes (Mexico)</td>
<td>Luis Ortega Reyes</td>
</tr>
</tbody>
</table>
7. Update on IRC History compilation

Jim O’Rourke reported that the History has been updated from the early History that had been compiled after the first 4 congresses. This updated History is to be included in the proceedings of this Congress.

8. Update on scanned of Congress Proceedings (past & current)

Ray Smith has organized for the proceedings of this Congress to be scanned by the University of Kentucky. Congresses since Hohhot in 2008 have been produced electronically but it is unclear if these can be accessed by the worldwide audience. Funding is needed to digitize earlier congresses.

9. No constitutional amendments were received prior to the 6 months preceding the IRC 2021 meeting, therefore there will be no changes to the constitution.

10. Presentation from IRC 2025 Australian Organizing Committee

David Phelps presented the Welcome to attend the IRC Congress to be held in Australia in 2025.

11. At the Friday, October 29, Meeting of the CC David Phelps was elected to serve as President and Robin Reid as Vice President of the IRC CC until and including the next Congress in Australia in 2025.

12. Minutes of the Final Business Meeting, Kenyan IRC—Friday 29 October 2021 (Saturday 30 October 2021 AEST)

Agenda:
- Vote of revised Resolution 6
- Finalise voting procedure and ratification of new committee members

Meeting opened: 1.15 am AEST (GMT+10)

Apologies: none received

Attendance (as per on-line platform at start of meeting):
- Otto Kaufmann
- Gaci Dihia
- Abdelmajid Bechchar
- Adubeker Hassen
- David Phelps
- George Keya
- Elly Sabiliti
- Mounir Louhaichi
Please note: 33 people actively in attendance. Another 69 people had entered the meeting at some point (names were not recorded).

Dana Kelly opened the meeting by welcoming all delegates and noting there would be a meeting of the new committee at the end of this meeting. It was noted that all delegates are welcome to attend both meetings. Dr Kelly explained that voting needed to be re-done for the revised Resolution 6. Whilst this was put to the First business meeting on Wednesday and passed, the voting results were not recorded in the system.

Dr Kelly then opened the floor for discussion (via the type-in discussion facility online).

Voting proceeded.

**Revised Resolution 6 was passed unanimously.**

Dr Kelly then formally opened the procedure to appoint new committee members. She thanked the outgoing members: Anthony Palmer; Mounir Louhaichi; Ayurzana Enkh-Amgalan; Fujiang Hou; Elisabeth Huber-Sannwald; Cristina Genro; Susana Feldman; James Bennett; and noted that she had also completed the maximum allowed two terms on the IRC CC.

Dr Kelly then explained that nominations for committee positions had been requested prior to the First business meeting through all IRC CC representatives. This was a pragmatic decision to ensure enough time to implement the polling procedure on the virtual platform. Nominations were received for each region prior to the First Business meeting.
Nominations had been ratified and voted on at the First Business Meeting on Wednesday. However, a nomination was received during the first business meeting. This is allowed under the IRC CC constitution and therefore needed to be considered. It was acknowledged that it was possible that not all delegates had received fair notice to lodge nominations prior to the First business meeting.

The IRC CC nominations committee met out of session and determined that all existing and new nominations should be reconsidered at the Final business meeting on Friday, to ensure procedural fairness under the constitution.

In a first for the IRC CC, there was a tied vote during the First meeting, between Brandon Bestelmeyer (USA) and Luis Ortega (Mexico) who were both nominated as representatives for the America: North and Mexico region. A second call for nominations was issued to all delegates via the virtual platform notification system during Thursday 28 October 2021. This second call closed at 7pm (EAT, GMT+3) Thursday 28 October 2021. Prior to the close of the second call for nominations, Brandon Bestelmeyer (USA) withdrew to ensure the successful nomination of Luis Ortega and that the North American region retained representation from Mexico.

All other previously received nominations were noted as received. One additional nomination that met all requirements was received, which triggered the need for a vote on the representative for the Southern Africa and Sub-Saharan Africa region.

Dr Kelly read the list of nominees where voting was not required, and the meeting welcomed the following new committee members by acclamation:

- Nicole Spiegel (Australia/Oceania)
- Nahid Naghizahed (Africa: Northern Africa and Middle East)
- Tungalag Ulambayar (Asia: Central Asia and Mongolia)
- Yongfei Ba (Asia: China and East Asia)
- Luis Ortega (America: North and Mexico)
- Diego Bendersky and Walter Ayala (South America, two vacancies)
- Pablo Manzano Baena (Europe)

Dr Kelly called for nominees or others to discuss the two nominations for the Southern Africa and Sub-Saharan Africa region, via the type-in discussion facility.

Voting was then opened, with sufficient time given for all delegates in attendance to vote. The final displayed vote was 72% in favour of Igshaan Samuels and 28% in favour of Abubeker Hassen. It should be noted that the voting system did not allow voters to change their vote.

Dr Kelly announced that Igshaan Samuels led the poll by a substantial margin and that an official statement would be provided once the count was finalised after the meeting closed. Dr Kelly thanked both candidates for their interest in contributing to the international community through the IRC CC.
Dr Kelly, then announced that the position of President and Vice-President were vacant, and called for nominations to the position of President.

Robin Reid (USA) nominated David Phelps of Australia. Dr Phelps accepted the nomination. Delegates were then given time to offer additional nominations; none were received. Dr Phelps was ratified by acclamation as President until the next IRC. Dr Kelly then stepped down as chair of proceedings and Dr Phelps assumed the role and oversaw voting for the position of Vice-President.

Dr Phelps called for nominations to the position of Vice-President. Nicole Spiegel (Australia) nominated Robin Reid (USA). Dr Reid accepted the nomination. Delegates were then given time to offer additional nominations; none were received. Dr Reid was ratified by acclamation as Vice-President until the next IRC.

A motion of congratulations and gratitude for the work of Dr Dana Kelly as President for 2016-2021 was moved by David Phelps, seconded by Robin Reid and supported by acclamation and expressions of support from the meeting delegates. A motion of gratitude for the decades of hard work and support to the committee by James (Jim) O’Rourke as IRC CC Secretariat was moved by Dana Kelly and seconded by Robin Reid and resoundingly supported by acclamation and expressions of support from the meeting delegates.

The meeting was closed at 1.36am AEST (GMT+10).

All delegates were invited to stay for the first meeting of the new IRC CC.
Minutes of the first IRC Continuing Committee Meeting with the 2021-25 committee, Kenyan IRC—Friday 29 October 2021

The first meeting of the new IRC CC (2021-2025) was then held, chaired by Dr Phelps. It was noted that all delegates were welcome to attend and to provide discussion.

International Rangeland Congress Continuing Committee (IRC CC)

First business meeting of the 2021-25 committee, Kenyan IRC—Friday 29 October 2021

Meeting opened: 1.37 am AEST (GMT+10)

Apologies: none received

Attendance (as per on-line platform at start of meeting):

- Ann Waters-Bayer
- Anna Seidel
- Bernard Hubert
- Cecilia Turin
- David Briske
- David Phelps
- Diego Bendersky
- Elly Sabiliti
- Gabriel Olivia
- Gaci Dihia
- George Keya
- Jacob Barasa Wanyama
- James O’Rourke
- Luis Ortega Reyes
- Mohamed Tarhouni
- Nicole Spiegel
- Robin Reid
- YongFei Bai
- Solomon Tefera Beyene
- Yohana Ogom
- Caroline Kute
- Jose Luis Zaragoza Ramirez
- Mulisa Faji Dida
- Tungaa Ulambayar
- Walter Ayala

Dr Phelps noted his intention to build the committee as team based on shared values, goals and actions; to work to implement the Resolutions passed at the Congress; and to work with the Australian Organising Committee and the International Year or Rangelands and Pastoralists support groups to support successful events and raise the profile of rangelands and pastoralists over the coming years.

Dr Reid noted her intention to lead the implementation of more formal structure for the IRC CC and of the Resolutions passed.
Both noted that there are many passionate, dedicated and innovative professionals globally whose assistance to the IRC CC will be gratefully accepted to deliver this agenda of enhancing the capacity and impact of the IRC CC.

Meeting closed 1.59am AEST (GMT+10).

International Rangeland Congress Continuing Committee members (2021 - )

<table>
<thead>
<tr>
<th>Region</th>
<th>Outgoing member 2011-2021</th>
<th>Continuing member 2016-2025</th>
<th>Nominations 2021-2029</th>
<th>New member 2021-2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia/Oceania</td>
<td>Dana Kelly</td>
<td>David Phelps</td>
<td>Nicole Spiegel</td>
<td>Nicole Spiegel</td>
</tr>
<tr>
<td>Africa: Southern Africa, Sub-Saharan Africa</td>
<td>Dr Anthony R Palmer</td>
<td>George Azenga Keya</td>
<td>Igshaan Samuels</td>
<td>Igshaan Samuels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Abubeker Hassen</td>
<td></td>
</tr>
<tr>
<td>Africa: Northern Africa and Middle East</td>
<td>Mounir Louhaichi</td>
<td>Mohamed Tarhouni</td>
<td>Nahid Naghizahed</td>
<td>Nahid Naghizahed</td>
</tr>
<tr>
<td>Asia: Central Asia and Mongolia</td>
<td>Ayurzana Enkh-Amgalan</td>
<td>Dildova Aralova</td>
<td>Tungalag ULAMBAYAR</td>
<td>Tungalag Ulambayar</td>
</tr>
<tr>
<td>Asia: China and East Asia</td>
<td>Fujiang Hou</td>
<td>Guodong HAN</td>
<td>Yongfei Ba</td>
<td>Yongfei Ba</td>
</tr>
</tbody>
</table>
| America: North and Mexico                  | Elisabeth Huber-Sannwald  | Robin Reid (USA)            | Brandon Bestelmeyer (USA)  
(withdrew following a tied vote)  
Luis Ortega (Mexico)                       | Luis Ortega               |
| South America                              | Cristina Genro            | Diego Bendersky             | Walter Ayala           | Walter Ayala          |
|                                            | Susana Feldman            |                             |                        |                       |
| Europe                                     | Dr James Bennett          | Bernard Hubert              | Pablo Manzano Baena    | Pablo Manzano Baena   |
Joint International Grassland and International Rangeland Congress Kenya 2021: Grasslands Summary

Klotz, J. L.¹; Bouton, J. H.²

¹ USDA - Agricultural Research Service, Forage-Animal Production Research Unit, Lexington, KY, USA
² Institute of Plant Breeding Genetics and Genomics, University of Georgia, Athens, GA, USA;

Key words: cultivated grassland; livestock; production; sustainability

Abstract

This summary used as its main sources the plenary and keynote papers and talks in Sub-theme 2: Forage Production and Utilization and Sub-theme 3: Livestock Production Systems as well as a sampling of oral talks presented at the XXIV International Grassland Congress (IGC). This IGC was held virtually and jointly with the International Rangeland Congress and hosted in Nairobi, Kenya during 23-29 October 2021. The XXIV IGC was also the first to be held on the African continent in Congress' 94-year history. The summary is further focused on that information presented under the concept “cultivated grasslands” (e.g., a small number of species exposed to high management inputs) and is independent of the rangeland summary presented elsewhere in these proceedings. As with all previous IGCs, pasture productivity, quality, and persistence were emphasized, but understandably, mainly for aspects relevant to Africa and the tropics. However, carbon sequestration, pasture resilience, adaptation, and greenhouse gas mitigation were addressed as part of cultivated grassland management. These additional concerns will challenge everyone as new technological advances are deployed into global agriculture. Impacts on social, environmental, and economic issues remain important, but ill-defined. Future considerations include improving research and out-reach programs for the tropics, but especially adaptation of both tropical and temperate systems to projected climate change issues such as higher temperatures and inconsistent rainfall for all geographies. Fitting the current sustainability narrative to the science and not the other way around is important going forward. Finally, one must keep in mind how pastoralists and producers will be impacted with any future research projects and policy changes.

Introduction

The objective of this paper is to provide a summary that highlights important topics and key points pertaining to grasslands that were presented in the 2021 Joint IGC and IRC. Out of the 7 keynote presentations, 173 oral presentations, and 219 poster presentations, a definition of what constitutes a grassland compared to a rangeland would be needed. Using the broad differentiation between grassland and rangeland as cultivated versus native ecosystems (Caradus, 2021), this summary focused on “cultivated grasslands”.

Cultivated grasslands are often made up of a small number of plant species, management is normally intensive and the inputs are high, whereas rangelands are complex ecosystems consisting of numerous plant species, management is extensive, and there are limited inputs. With this definition in place, the focus for this summary centered on the plenary address by Jank, et al. (2021), and the keynote addresses by Caradus (2021), and Smith (2021) as well as highlights of talks from Sub-theme 2: Forage Production and Utilization and Sub-theme 3: Livestock Production Systems.

Cultivated Grasslands: Plenary and Keynote Addresses

Looking back at the 10th IGC in Helsinki, Finland (1966), Finland’s Minister of Agriculture emphasized “Grassland research in Finland should be intensified with the objective of increasing yields per hectare, as well as improving the quality and efficiency of utilization” (Allen, et al., 2021). This prevailing attitude of the time
was probably bolstered by the commonality that most of the attendees had first-hand experiences of how World War II devastated the food supplies across the globe. There were also predictions by Paul Ehrlich and others, promoted extensively by the press, of looming worldwide famine due to human over-population. That mindset led to the Green Revolution, and an emphasis on high yields and the use of fertilizers that likewise put a heavy importance on maximizing production of cultivated grasslands.

Fast-forward 55 years to the current 2021 Joint IGC-IRC in Kenya where the plenary address by Jank (2021) defined new standards for cultivated grasslands. Similar to the standards defined at the Helsinki congress, there remains an emphasis on pasture productivity, quality, and persistence, but now an added emphasis on carbon sequestration, pasture resilience, adaptation, and greenhouse gas mitigation. Also, novel compared to the Helsinki congress was how pasture sustainability will contribute to positive social, environmental, and economic impacts. Thus, there has been a notable shift from a singular focus on maximizing pasture productivity to now include sustainability of cultivated grasslands and how this fits into the global ecosystem.

In his keynote address, Caradus (2021) went further and defined challenges for the new standards within cultivated grasslands. With the new emphasis on enhanced environmental consciousness, caution is warranted. The integration of large numbers of agritech developments into current pastoral systems may have unintended consequences that negatively impact sustainability of grasslands. This will challenge farmers and society as whole.

In his keynote address on livestock production, Smith (2021) encouraged the engagement of critics on the facts surrounding livestock impacts on greenhouse gas production as well as sustainability. To meet sustainability goals and continue to reduce greenhouse gas emissions, production on a per animal basis must be increased.

For the topic Grass Research in Kenya and Other African Countries, it was shown that starting in Brazil in the 1950s, the two grass genera (*Urochloa* and *Brachiaria*) have continued to expand their use and importance throughout the tropics. There was excellent research presented from Kenyan scientists on agronomic studies to determine growth, production, and utilization in Africa, as well as evaluating new cultivars. There still seems to be confusion over taxonomy differences between the two genera that needs to be resolved.

For the topic Tropics and Tropical Genetic Resources, several talks reemphasized the importance of tropical agriculture and especially the conservation and stewardship of its genetic resources. More collections are needed, and accessions identified and curated. Gene banks need to be better funded and resourced.

For the topic Forage Breeding and Genetics, reviews were presented around temperate/tropical breeding successes. There was also a continued emphasis from past IGC conferences on implementing modern forage improvement methods, including biotechnologies, but not at the level of recent previous IGC conferences. However, this is to be expected with the Congress’s emphasis on tropical species where applications (and costs) for biotechnologies are still to be determined.

For the topic Forage Legumes for the Tropics, the greatest challenge is to increase the adoption and use of forage legumes especially tropical legumes. Research on grass-legume mixtures found that they are still the best way to increase fodder nutritive quality and reduce N fertilizer use but were also reported to achieve positive greenhouse gas balances.

For the topic Grass Research in Kenya and Other African Countries, it was shown that starting in Brazil in the 1950s, the two grass genera (*Urochloa* and *Brachiaria*) have continued to expand their use and importance throughout the tropics. There was excellent research presented from Kenyan scientists on agronomic studies to determine growth, production, and utilization in Africa, as well as evaluating new cultivars. There still seems to be confusion over taxonomy differences between the two genera that needs to be resolved.

For the topic Tropics and Tropical Genetic Resources, several talks reemphasized the importance of tropical agriculture and especially the conservation and stewardship of its genetic resources. More collections are needed, and accessions identified and curated. Gene banks need to be better funded and resourced.

For the topic Forage Breeding and Genetics, reviews were presented around temperate/tropical breeding successes. There was also a continued emphasis from past IGC conferences on implementing modern forage improvement methods, including biotechnologies, but not at the level of recent previous IGC conferences. However, this is to be expected with the Congress’s emphasis on tropical species where applications (and costs) for biotechnologies are still to be determined.

For the topic Forage Legumes for the Tropics, the greatest challenge is to increase the adoption and use of forage legumes especially tropical legumes. Research on grass-legume mixtures found that they are still the best way to increase fodder nutritive quality and reduce N fertilizer use but were also reported to achieve positive greenhouse gas balances.

Cultivated Grasslands: Sub-Theme 3: Livestock Production Systems Highlights

There were 27 oral presentations and 29 posters presented in 7 topic areas for this sub-theme. One issue that emerged was around the topic of management intensive grazing where there is not a global one size fits all scenario. Short-term high-performance pastures are a great example of pushing animal production on pasture to their genetic limit while taking advantage of environmental opportunities. As climate patterns continue to produce larger weather extremes, methods to take maximum advantage of environmental opportunities must continue to be explored. In addition to weather, identification
of stakeholder socio-economic hurdles that limit pasture-based livestock production in economically challenged regions of the world must continue. Advances here will permit producers to not only feed their family, but make a profit as well as contributions to feeding the global population.

Another important topic in several presentations was balancing production and sustainability where short-term gains result in long-term losses if maximal productivity is favored over sustainability. Rest-grazing systems were also reported to achieve greater productivity in the long-term compared to continuous grazing. As intensification continues, one must not be tempted by short-terms gains. Producers must continue to explore opportunities to bring grazing animals back to pasture, such as in intensive dairy operations where meat production on pasture could be optimized alongside production of dairy products.

Under a topic that could be labelled as drought, desertification, and degradation, there has been an unfortunate narrative change over time. The narrative evolved from an example of short-term gains in livestock productivity favored over long-term sustainability of the grassland through overgrazing and overuse contributing to degradation and desertification of pastures to a narrative where grasslands were an environmental solution as an ideal use of land in increasingly harsh climates. Now grasslands used for livestock production are again being criticized as a greenhouse gas source problem. This needs to change through educating policy decision makers and the general public that the coexistence of grassland and livestock management is still a solution to land degradation. Implementing drought-risk financing to build resilience was a very good suggestion.

**Conclusion**

Future considerations for the IGC include improving research and out-reach programs for the tropics as well as how cultivated grassland can adapt to the current climate change narrative, especially the projected higher temperatures and inconsistent rainfall. Grassland scientists must also fit the sustainability narrative to the science and not the other way around, and scientists must not forget the pastoralists and how they can capitalize on possible future economic opportunities such as carbon sequestration. All grassland scientists must continue to do good science, communicate findings to peers and decision makers, and steer the current sustainability narrative in the right direction, possibly even into the schools.

**Acknowledgement**

The Kenyan organizers are to be congratulated for being the first to host an International Grassland Congress on the African Continent in the 94-year history of the Congress (Allen et al., 2021). That it was held virtually and during a global pandemic with few interruptions was a technological triumph and a model for others to follow.

**References**


Key Issues Generated from the XI International Rangeland Congress 2021: Summary and Way Forward

Coppock, D. L.,1; Ash, A. J.,2; Irving, B.3

1Professor Emeritus, Dept. of Environment and Society, Quinney College of Natural Resources, Utah State University, UMC 5215 Old Main Hill, Logan, UT USA 84322-5215; Layne.Coppock@usu.edu

2Honorary Professor, The University of Queensland, 306 Carmody Rd, St Lucia, QLD 4061 Australia andrew@ajashassociates.com

3Retired Director, Agricultural Research Stations, University of Alberta, Canada birving@ualberta.ca

Key words: IRC 2021 global review; important issues, knowledge gaps, evolving research approaches on rangelands; social-ecological systems on rangelands

Abstract

The important issues, knowledge gaps, and evolving research approaches for the global rangelands are summarised in this review of submissions to the Joint XXIV International Grasslands and XI International Rangelands Congress (IGC/IRC). In the big picture, it is concluded that stand-alone studies of livestock production are becoming rare compared to that of the past International Rangelands Congresses (IRC). Rather, added effort is now being directed at understanding the fuller context of social-ecological systems (SESs) on rangelands in a quest to improve the prospects for sustainable resource management as well as the enhancement of human welfare. Although climate change is upon us, there was still a dearth of papers that dealt with broad- scaled climate-adaptation per se; opportunities to improve local drought response were the default topics here with a focus on implementing better drought early warning systems and integrating perspectives among producers and scientists. Invasive species challenges remain as prominent global concerns, and woody encroachment is viewed as a major contributor to rangeland degradation. Treatments to combat rangeland degradation can involve innovative layering methods incorporating grazing management and use of prescribed fire. While there is an important backdrop concerning ecosystem services from rangelands, research in this area is still in its infancy. Analysing trade-offs between production and conservation for services such as carbon sequestration loom large going forward. There were relatively few papers concerning wildlife, tourism, and associated issues; successes and challenges for natural resource conservancies were noted, in particular. These are topics that merit more creative research and development attention in the future. Some contributions highlighted the important issue of landscape conversion from rangelands to cultivation; in conjunction with human population growth, loss of such key resources can be very negative for wildlife and associated values. In terms of pastoralism and related sub-themes, while it was noted that the majority of studies now embrace SESs and integrated, participatory, action- oriented approaches, there is little effort to standardize methodologies. A focus on repeatable methods can help grow “sustainability science” on rangelands, and this is a challenge for research and outreach education. The volume of studies submitted overall indicated a decided numerical advantage for the Global South over the Global North. Why this is the case remains unclear, however. Disciplinary research traditions in wealthier nations may not yet provide the incentives needed to spur innovative SES work. Finally, policy makers are seen by many investigators as being ignorant of rangeland development issues. It is argued, however, that this view has not changed for 40 years. How to better engage policy makers in comprehensive SES projects is an important future goal. Policy makers themselves can then
also become human research subjects in the overall process. Based on our review the future for IRC stakeholders is clear: Continue the expansion of interdisciplinary SES and action-based approaches and increase attention to climate-change adaptation/mitigation, ecosystem services, community-based development, human empowerment, market development, poverty mitigation, and creation of effective policy frameworks.

**Introduction**

The rangelands component of the IGC/IRC congress was organized around six of the seven sub-themes as follows: (1) Rangeland ecology; (3) Livestock production systems; (4) Wildlife, tourism, and multi-facets of rangelands; (5) Drought management and climate change in rangelands; (6) Pastoralism, social, gender, and policy issues; and (7) Capacity, institutions, and innovations for sustainable development of rangelands. The co-authors of this summary paper were asked to review a sample of contributions and identify important issues, knowledge gaps, and evolving research approaches. This process would help identify a way forward for future congresses.

**Methods**

Authors were assigned different sub-themes to review. There was flexibility in what could be emphasized. Ash and Irving examined submissions for sub-themes (1) and (3) to (5) to identify key, recurrent insights, assessing 103 papers and 50 posters in total. In contrast, Coppock examined submissions for sub-themes (6) and (7) with a focus on the global distribution of work and the evolution of field methods.

**Findings**

**Sub-theme: Rangeland Ecology**

A sample of 49 submissions in this category were reviewed. As expected, the breadth of topics covered was too great to be captured in detail here. Thus, this review is limited to general observations. Although the keynote speaker for this sub-theme (Smith, 2022) noted that rangeland systems degraded from overuse by livestock comprise only a small portion of global resources, singular studies indicate that rangeland degradation remains as a serious challenge (Treydte et al., 2022). One common form of rangeland degradation continues to be invasion by woody species. This ecological transformation is almost universally viewed as negative. One paper in this group, however, noted an improvement in rangeland condition associated with an increase in tree cover for an area that had endured extreme woody reduction due to cutting for fuel, building materials, and overgrazing (Nyaga et al., 2022). Invasive species are commonly noted as being a significant threat to global biodiversity, possibly second only to impacts from climate change (Mutua and Chiuri, 2022). A new invasive species that has moved from South America to Kenya (Parthenium hysterophorus) represents a trajectory from the New World to Old World that is a contrast to patterns typically reported. Overall, land-use change continues to be a concern for ecologists, especially for places that occur on the productive interface between agriculture and rangelands (also see below). Finally, climate change has been speculated to reduce the resilience of global rangelands in response to what one paper described as system shocks (Treydte et al., 2022) such as severe drought or catastrophic fire.

The compendium of papers in the ecology theme covered a wide variety of topics that were significant in expanding global science. One subset of work can best be described as descriptive studies of the physical environment. Alamin and Hassan (2022) described a new rangeland type in Sudan, while Mitchell et al. (2022) reminded us that the occurrence and germination of plants from a soil seed bank in Australia does not have the same dominance pattern as occurs in the parent sward. In other words, perennial species were poorly represented in seed banks that were dominated by ephemeral species.

There was another suite of papers dealing with livestock grazing behaviour on rangelands, many of which were focused on investigating locally adapted animals. Some studies investigated influences of novel livestock species, mostly documenting introductions of small ruminants into systems previously dominated by large ruminants (Schneider et al., 2022). Other studies examined novel strains of animals within the same species that are well-adapted to local situations (Pauler et al., 2022). Locally adapted strains were generally already known to local producers, but initially unknown to researchers. Novel situations were also detailed where established management practices, such as multiple cutting of brush, were deployed in new and different environments (Wedel et al., 2022).

There were also descriptive studies of practices to better manage rangelands. Treatment layering—namely, the application of simultaneous or subsequent sets of treatments to help manage or solve the same rangeland problem—was commonly reported, especially for woody invasion challenges (Wedel et al., 2022). Treatment layering could be comprised of repeated applications of
prescribed fire, prescribed grazing, or livestock herding in various combinations. Kreuter et al., (2022) described use of community-based, prescribed-burning associations to enhance the use of prescribed fire where periodic mitigation of catastrophic fire events is required. Community-based approaches can help spur adoption of prescribed fire methods by spreading the risk from a few individuals to a larger group of resource users.

Climate-change mitigation and drought readiness was a common theme amongst numerous studies (Oliva and Gaitan, 2022; Muller et al., 2022), with some duplication with submissions to other sub-themes (see below). The Ecology section papers mostly studied soil carbon and its response to various grazing regimes or treatment applications, information that could be used to aid predictions for a more global discussion of climate change. In general, moderate stocking is promoted as a means for rangeland managers to better survive droughts and promote soil carbon storage (Liu et al., 2022). Providing support for traditional grazing practices was another common research topic. Some studies promoted expansion of deferred grazing systems via the use of livestock exclosures (Abdulahi et al., 2022). Others investigated constraints limiting a return to traditional grazing practices based on restoration of mobility (Manzano et al., 2022). While the benefits of mobile pastoralism are well appreciated in many systems, it is also true that traditional grazing practices based on sedentary attributes can also be valued. Sometimes thresholds based on human population growth or intensive resource use may be crossed to a point where a return to historical practices (i.e., mobility) is no longer possible.

**Sub-theme: Drought Management and Climate Change**

Adapting to droughts, climate variability, and climate change with appropriate and timely management strategies is a huge challenge for rangeland managers and pastoralists. This is especially true for those managing livestock where the base forage supply is already highly variable from year to year. Materials reviewed here include a plenary talk (Howden, 2021) along with a sample of 18 oral papers and 22 posters.

Effective drought management requires early action. Whilst many such actions have been identified, Bulle (2022) argued that drought management strategies to reduce livestock mortalities—including destocking programs, supplementary feeding, provision of early warning information, water development, and veterinary services—are usually introduced too late during drought events and most have little emphasis on ecosystem sustainability. Attempts to identify early warning tipping-points in ecosystems to help inform timely actions are elusive (Klingenfuss, 2022). In developing drought management strategies, there needs to be better integration of producer expertise with science-based approaches. This was highlighted in a study by Brinkmann et al. (2022) who noted the challenges of differences in coping strategies, with pastoralists or farmers focused on short-term responses while scientific experts promoted longer-term management strategies.

In his plenary address, Howden (2021) highlighted changes in rainfall variability will have as much impact on rangelands as will changes in total rainfall. Further, changes in rainfall seasonality patterns will likely cause changes in plant species composition of rangelands (Zhou and Du, 2022). The most damaging trends for livestock production will occur in rangeland regions that are already the most vulnerable in terms of productivity and socio-economics (Godde et al., 2022).

Adapting to climate change will be crucial if livelihoods from rangelands are to remain viable. However, very few oral papers at the congress addressed climate adaptation measures. A few of the poster papers did provide some options on better managing forage supply in response to a more variable climate. A large diversity of adaptation options on- and off-farm (or ranch) have already been developed, including approaches that vary from tactical to strategic and incremental to transformational (Howden, 2021). Working with ranchers shows that positive outcomes can be achieved where there is a focus on implementing practices that increase resilience to climate change while balancing other risks (Brinkmann et al., 2022). Other studies highlighted the importance of understanding the limits to climate adaptation, how to remove barriers to adaptation, and how to better integrate adaptation strategies with emission-reduction strategies for greenhouse gases.

Climate change mitigation options include improved farm or ranch management, direct reductions in methane from livestock, carbon sequestration in soils and vegetation, and reducing losses and wastage in food systems. Results from Kenya (Ndung’u et al., 2022) showed that emissions from livestock systems are highly variable, and in a conclusion that challenges conventional wisdom, the best low-input systems can be as emission-efficient as industrial-style intensification. Increasing soil carbon in rangelands has production trade-offs, and increasing woody vegetation (i.e., Leucaena...
hedgerows in semi-arid rangelands) doesn’t always lead to significant increases in soil carbon (Banegas et al., 2022). Further, using rangelands for carbon sequestration needs to consider future climate change to ensure optimum landscape use for carbon abatement, but this issue is rarely considered in policy-led, carbon sequestration initiatives (Waters et al., 2022).

**Sub-theme: Livestock Production Systems**

Livestock production has been a major area of interest in past rangeland congresses. In this congress, however, there were just 18 studies submitted with only four focused on the biophysical aspects of increased livestock production. The remaining 14 contributions covered broader aspects of livestock production including grazing systems, sustainability, crop-livestock interactions, food security, livestock-wildlife interactions, socio-ecological drivers, and market interactions.

In his plenary address, Smith (2022) highlighted that despite societal concerns about environmental challenges of livestock production, in rangelands livestock help support the livelihoods for 200 million households globally. Rangeland production systems can also provide co-benefits from ecosystem services (i.e., carbon sequestration and biodiversity). A number of papers and posters were focused on how grazing management can achieve both production goals with improved environmental outcomes. Most studies suggest that balancing forage production with stocking rate is key, with the grazing system per se being of less importance for production, although rest from grazing can benefit land condition and plant species richness (McDonald et al., 2022).

Whilst grazing systems receive much attention in the rangelands of wealthier nations, a large global survey of producers identified feed shortages as the main constraint to improved livestock productivity in Africa and Asia. Improvements in livestock productivity require a comprehensive systems approach that addresses all constraints simultaneously i.e., nutrition, genetics, health, finance, markets (Duncan, 2022). The concept of systems approaches to achieve better outcomes in livestock production has led to the development of various frameworks to assess multiple values, benefits, and trade-offs to help decision-making where rangelands are providing multiple functions (i.e., wildlife habitat, symbiotic reciprocity among different users—Wedderburn et al., 2022; Michler et al., 2022; Malhotra and Nandigama, 2022). Smith (2022) concluded that for livestock systems in rangelands to be sustained, rangeland managers and pastoralists need to embrace change, harness diversity, and engage widely with different stakeholders.

**Sub-theme: Wildlife, Tourism, and Multi-Facets of Rangelands**

This is another relatively small category with only 18 papers submitted. Key issues, however, are apparent. In general, it is almost universally accepted that any practice, policy, or application that maintains open spaces on grasslands and rangelands will be good for wildlife and other non-agricultural goods and services (Reid, 2022). Community-based tourism—where local communities are intricately involved in the management of local resources, including large wildlife species—is a research topic of intense interest, especially in Africa (Das, 2022).

Conservancies are a specialized form of community-based tourism. Conservancies are relatively common in Africa and specific examples are provided by Parmisa and Kitengela (2022). There have been successes in adding value for large wildlife species for local communities so that systems can better tolerate negative effects of livestock on natural ecosystems. There is cause for concern, however, as some conservancies in dry lands are also being transformed to towns and croplands as human populations grow. For example, local herding groups can become villages, villages can become towns, and there is a general tendency for agriculture to expand—all of which can result in a reversal of conservancy benefits for wildlife (Galvin, 2022).

The challenge of rangeland cultivation and land-use conversion to annual crops was also noted as a rapidly developing problem in the Pampas of Brazil, where highly productive native grasslands are being converted to soybean plantations (Moreira et al., 2022). The dynamic challenges of such land conversions are apparent in this example, as cultivation of soybean destroys natural vegetation, raises land prices, and changes the landscape and habits of producers. In addition, the conversion process diversifies production and generates more income for ranchers, who then become mixed farmers who need to create marketing and fodder alternatives for cattle (Moreira et al., 2022). Local wildlife (some of which are migratory) then absorb the loss of resources while the local economy receives the gains. This may be a situation that is playing out on a global scale.

Papers that document problems associated with the conversion of rangelands to cultivated fields may be the most consequential for this congress. They collectively point to incremental changes
that might be indicative of much larger challenges to come. Perhaps one statistic can summarize where rangelands and the associated wildlife are at on a global scale, namely that an incredible 96% of all mammalian biomass on the planet now comprises by either humans or their livestock (Treydte et al., 2022). That fact should make us wonder where large wildlife populations and associated suites of other natural life forms is headed, given that human populations continue to grow, requiring that range landscapes be converted to farming.

**Sub-themes: Pastoralism, Social Issues, Institutions, and Innovations**

The focus in this sub-theme shifts to an analysis of the global origins of papers as well as an overview of evolving research approaches.

The 62 papers reviewed for these sub-themes were unevenly distributed around the globe. There were considerably more submissions overall from the Global South when compared to that for the Global North. Only 11 percent originated from North America and Europe, while over half (54 percent) originated from Africa, Latin America, the Middle East, and central or southern Asia. There were no submissions from Australia (Fig. 1).

![Figure 1. Global distribution of 62 paper submissions by region for pastoralism and related topics, Joint XXIV IGC and XI IRC, October 2021.](image)

Sixteen percent of papers offered a global perspective, while the rest were specific to regions, nations, or localities. Overall, the attention given to different biomes was fairly well balanced considering temperate, tropical, or subtropical situations. For example, temperate settings were well-represented by China, Mongolia, Central Asia, North America, Europe, and parts of the Middle East. The tropics and subtropics were well-represented by Africa, Latin America, and southern Asia.

In terms of research approaches, 73 percent of papers were based on mixed methods (i.e., social and environmental sciences). Twenty-five percent of papers were only based on social science. Two percent were only based on environmental science (i.e., ecology, biology, climate, etc.).

Social science questions and methodologies thus dominated these submissions overall. Examples of common social-science perspectives included a focus on livelihoods, policy constraints, gender, co-production of knowledge, participatory research, governance, valuation of ecosystem services, political constraints, and creation of human and social capital. Research methods relied heavily on social surveys, interviews, focus groups, participatory engagement, action research, land-use planning, and role playing among project stakeholders. In seven percent of cases research involved use of simulation models to organize research and illustrate support for recommendations.

**Discussion**

A significant number of papers in the Ecology stream (Theme 1) is an extension of current knowledge into new regions. Some specific examples are new description of seed bank responses, new examinations of locally adapted species and strains of livestock, and applications of established methods such as prescribed fire or targeted grazing to new areas for woody control, rangeland use enhancement, or improved livestock production. Climate change mitigation and adaptation is perhaps a new theme to an old challenge of drought preparedness. There was a recurring observation, evident in several papers, that moderate stocking rates by livestock improved sustainability as reported in new research (enhanced carbon sequestration) and to manage old challenges (ability to withstand drought). There is also a resurgent interest in practitioner knowledge and a return or maintenance of
locally sustainable management practices as a way forward for many rangeland management challenges.

Although livestock production remains a critical output from the global rangelands, research on how to improve animal performance was only a minor component of this IRC. This reinforces a trend of placing range livestock production in a broader ecological and social context. This pattern has its origins following the II IRC (Adelaide) with a plea from Box (1986) who noted:

“It (this congress) did not adequately address rangeland products other than livestock. To focus on commercial pastoralism, a human lifestyle of developed nations, is to further marginalize the people issues of rangelands.”

Some traditional livestock or grazing issues, however, continue to receive attention after many decades of research and debate. For example, quantifying the advantages and disadvantages of different grazing systems still provokes considerable interest (di Virgilio et al., 2019), and this was also addressed at this IRC. This will likely remain as an important topic of future study, despite that livestock production in general may be receiving less attention.

Despite a clear appreciation of the emerging implications of global climate change (i.e., Howden, 2021; Godde et al., 2022), it was surprising that very few papers explicitly addressed climate adaptation options for pastoralists and other rangeland users. It is difficult to explain this anomaly, as there is an increasing number of studies in the wider literature on climate-adaptation for agriculture, including rangelands. A few papers here examined drought preparedness, raising the question: Does the lack of specific papers on climate-adaptation reflect a view that options for simply dealing with weather variability (i.e., droughts, floods, heat, etc.) are sufficient? Would it be disturbing if this is the case because the wider literature is quite clear about the urgent need for transformational change to address climate change in agroecosystems. Hopefully, there will be a stronger contribution on climate-change adaptation at the next IRC.

Overall, it is clear the vast majority of research approaches reviewed under the pastoralism and related sub-themes involved a robust mix of social science with environmental science. This makes sense given that most projects had a goal to improve resource management and/or livelihoods, and thus there is a need to better understand stakeholders and encourage long-term buy-in for sustainable problem-solving. This philosophy embodies a “social-ecological systems” (SEs) perspective (Ostrom, 2009; Partelow, 2018). In the big picture, this shift from traditional, descriptive, and disciplinary biophysical research (Box, 1986) to complex interdisciplinary work that tackles real-world problems is both necessary and remarkable. This indicates that the cadre of rangeland professionals attending the IRC has collectively embraced “research for development,” a new way of working advocated by Ashby (2003).

The SEs approaches employed by congress participants, however, are “organic” with respect to genesis and very diverse. This is understandable given the high diversity of investigators including researchers, practitioners, community members, etc. In most cases, there appears to be no reliance on a unifying scholarly SES framework (i.e., SEF; Ostrom 2009) that can be used to more efficiently to integrate social and environmental research components. The pattern for most studies at this IRC, rather, seems to be idiosyncratic as social science research is used to characterize the human dimensions of a certain situation, while environmental research is used to characterize the natural resource concerns. Cross-links between social and environmental spheres can thus be lost without a standard approach. One exception, however, is work carried out by Huber-Saanwald and colleagues (2019) where different research questions. There have been other attempts to distil a comprehensive SESF that can accommodate many types of natural-resource management situations and generate comparable sustainability indicators (Partelow, 2018). It may be useful if investigators study ideas embodied in the analysis by Partelow (2018) or adopt concepts from Ashby (2003) and use a more standardized SESF approach in the future. This can help grow “sustainability science” in the drylands (Ashby, 2003). Similarly, foundational approaches for “action research” (Whyte, 1989), participatory rural appraisal (Chambers, 1994), or innovation systems (Röling, 2009) are also uncited by IRC investigators. Embracing a standardized knowledge base and refining ways of working among peers is more likely to happen if there are incentives to do so. Incentives in this case can be facilitated by more education on SES and action-oriented methods for researchers, change agents, and community members.

Policy concerns are important in 61 percent of the papers in the subthemes covering pastoralism and related topics. And although policy concerns are a common backdrop for projects, “hard” policy analysis is very rare. Authors often contend that
policy makers do not understand or adequately value pastoralism or rangelands when making important decisions. This can lead to situations, for example, where key resources (i.e., water, land) are annexed from rangelands by external actors, resulting in the destabilization of pastoral production systems. That variable rangeland ecology requires producers to manage risk via mobility and household diversification appears to be under appreciated. Policy makers often come from non-pastoral backgrounds and lack the necessary frame of reference for decision-making concerning rangeland management or rangeland development. One intervention often forwarded by investigators is to better inform policy makers as to why rangelands and pastoralists are important and thus deserving of more aggressive and relevant policy support. Action-oriented interactions must replace our seemingly ineffective engagement with policy makers. We need to better understand the wants and needs of policy makers with respect to decision-making that affects the world’s rangelands.

The arguments about policy above make perfect sense, but such challenges have existed for many years (Galaty et al., 1981). We thus should ask ourselves why so little progress has been made? Alternative approaches for the next IRC (Adelaide 2025) could be to focus more attention on integrating policy makers into rangeland and pastoralism projects at the start, and make policy makers themselves another cadre of human subjects in SES investigations.

One last observation from the body of work concerning pastoralism and related sub-themes is why there is such an imbalance in the paper contributions from the Global North versus that for the Global South (Fig. 1). Rangeland systems in the developed world (i.e., Europe, USA, Canada, Australia) matter greatly, so why are their contributions relatively limited? One impression is that scholars in the developing world may more readily recognize the IRC as a key forum for their work, leading to more innovation in terms of adopting SES approaches. There are many possible reasons why such an unbalanced pattern occurs. The simplest explanation deals with scientific traditions. It is speculated that research in the economically developed Global North is more conventional and disciplinary in response to research funding that continues to emphasize technical studies, discount the human dimensions, and limit direct involvement with systemic problem-solving. The latter is neglected because of the high transaction costs of interdisciplinary or community-based research (Coppock, 2019). Research incentives in the Global North would need to change if the playing field is to be levelled with that of the Global South (Whitmer et al., 2010).

Conclusions

Based on our review, compared to the past, it appears that traditional, disciplinary studies focused on topics such as range livestock production, forage production, and grazing management have become more diminished. The trend in paper submission to the IRC is towards more social-ecological systems (SESs) research underpinned by interdisciplinary research. Social science investigation is increasingly based on community participation and action-oriented efforts to better engage stakeholders and solve problems. The reliance on SESs may, however, be strengthened as a form of “sustainability science” with more attention to methodological rigor. At the next IRC we fully expect that more attention will be given to topics such as climate-change adaptation and mitigation, ecosystem services, community-based development, human empowerment, market development, poverty mitigation, and creation of effective policy frameworks. More efforts are needed to better unite work in the Global North with that of the Global South.

Acknowledgements

The authors thank the many devoted professionals who contributed 399 papers and posters to the XI IRC. It is regretted that more insights from this large body of work could not be highlighted in this review. The authors also appreciate the opportunity to ponder key issues, knowledge gaps, and evolving research approaches as related to global rangeland systems for 2021.
References


## Membership of the National Organizing Committee of the Joint IGC-IRC Nairobi 2021

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Email Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Harry Kimtai</td>
<td>PS SDL</td>
<td><a href="mailto:pslivestock@kilimo.go.ke">pslivestock@kilimo.go.ke</a></td>
</tr>
<tr>
<td>Dr. Eliud Kireger</td>
<td>DG KALRO</td>
<td><a href="mailto:eliud.kireger@kalro.org">eliud.kireger@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Joseph G. Mureithi</td>
<td>KALRO</td>
<td><a href="mailto:mureithijg@gmail.com">mureithijg@gmail.com</a></td>
</tr>
<tr>
<td>Dr. Elkana Nyambati</td>
<td>KALRO</td>
<td><a href="mailto:elkana.nyambati@kalro.org">elkana.nyambati@kalro.org</a></td>
</tr>
<tr>
<td>Prof. Jesse Njoka</td>
<td>UoN</td>
<td><a href="mailto:jtnjoka@gmail.com">jtnjoka@gmail.com</a></td>
</tr>
<tr>
<td>Dr. Ann Notenbaert</td>
<td>CIAT</td>
<td><a href="mailto:a.notenbaert@cgiar.org">a.notenbaert@cgiar.org</a></td>
</tr>
<tr>
<td>Dr. Foustine Wandera</td>
<td>KALRO</td>
<td><a href="mailto:foustine.wandera@kalro.org">foustine.wandera@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Robinson Lance</td>
<td>Private</td>
<td><a href="mailto:l.robinson@ruwaza.com">l.robinson@ruwaza.com</a></td>
</tr>
<tr>
<td>Prof. Moses Nyangito</td>
<td>UoN</td>
<td><a href="mailto:mmnyangito@yahoo.com">mmnyangito@yahoo.com</a></td>
</tr>
<tr>
<td>Dr. Francesco Fava</td>
<td>ILRI</td>
<td><a href="mailto:francesco.fava@cgiar.org">francesco.fava@cgiar.org</a></td>
</tr>
<tr>
<td>Dr. Jane Wamuongo</td>
<td>KALRO</td>
<td><a href="mailto:janel.wamuongo@kalro.org">janel.wamuongo@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Dereje Wakjira</td>
<td>IGAD</td>
<td><a href="mailto:dereje.wakjira@igad.int">dereje.wakjira@igad.int</a></td>
</tr>
<tr>
<td>Dr. David Mwangi</td>
<td>KALRO</td>
<td><a href="mailto:david.mwangi@kalro.org">david.mwangi@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Samuel Mbuku</td>
<td>APSK/KALRO</td>
<td><a href="mailto:samuel.mbuku@kalro.org">samuel.mbuku@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Simon Onchiri</td>
<td>Immigration</td>
<td><a href="mailto:sonchiri@yahoo.com">sonchiri@yahoo.com</a></td>
</tr>
<tr>
<td>Prof. Cecilia M Onyango</td>
<td>UoN</td>
<td><a href="mailto:ceciliam.onyango@gmail.com">ceciliam.onyango@gmail.com</a></td>
</tr>
<tr>
<td>Mr. Davis Wambua</td>
<td>KICC</td>
<td><a href="mailto:wambua@kicc.co.ke">wambua@kicc.co.ke</a></td>
</tr>
<tr>
<td>Mr. Patrick Ngicuru</td>
<td>SDL</td>
<td><a href="mailto:patrickngicuru@yahoo.com">patrickngicuru@yahoo.com</a></td>
</tr>
<tr>
<td>Dr. Festus Murithi</td>
<td>KALRO</td>
<td><a href="mailto:festus.murithi@kalro.org">festus.murithi@kalro.org</a></td>
</tr>
<tr>
<td>Dr. George Keya</td>
<td>KALRO</td>
<td><a href="mailto:george.keya@kalro.org">george.keya@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Alice Murage</td>
<td>KALRO</td>
<td><a href="mailto:alice.murage@kalro.org">alice.murage@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Iain Wright</td>
<td>ILRI</td>
<td><a href="mailto:i.wright@cgiar.org">i.wright@cgiar.org</a></td>
</tr>
<tr>
<td>Mr. Stanley Humaiya</td>
<td>SDL</td>
<td><a href="mailto:humaiyalvsk2000@yahoo.com">humaiyalvsk2000@yahoo.com</a></td>
</tr>
<tr>
<td>Dr. Michael Okoti</td>
<td>KALRO</td>
<td><a href="mailto:michael.okoti@kalro.org">michael.okoti@kalro.org</a></td>
</tr>
<tr>
<td>Dr. Patrick Watete</td>
<td>SDL</td>
<td><a href="mailto:pwatete@gmail.com">pwatete@gmail.com</a></td>
</tr>
<tr>
<td>Ms. Florida Maritim</td>
<td>KALRO</td>
<td><a href="mailto:florida.maritim@kalro.org">florida.maritim@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Stephen Odipo</td>
<td>KALRO</td>
<td><a href="mailto:stephen.odipo@kalro.org">stephen.odipo@kalro.org</a></td>
</tr>
<tr>
<td>Ms. Helen Omukoko</td>
<td>KTB</td>
<td><a href="mailto:helen@ktb.go.ke">helen@ktb.go.ke</a></td>
</tr>
<tr>
<td>Mr. Isaac Masinde</td>
<td>Internal Security</td>
<td><a href="mailto:isaacmasinde0@gmail.com">isaacmasinde0@gmail.com</a></td>
</tr>
<tr>
<td>Mr. Moses Boit</td>
<td>KALRO</td>
<td><a href="mailto:moses.boit@kalro.org">moses.boit@kalro.org</a></td>
</tr>
<tr>
<td>Ms. Primrose Nabwire</td>
<td>KALRO</td>
<td><a href="mailto:primrose.wanyama@kalro.org">primrose.wanyama@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Richard Kedemi</td>
<td>KALRO</td>
<td><a href="mailto:ricahrd.kedemi@kalro.org">ricahrd.kedemi@kalro.org</a></td>
</tr>
<tr>
<td>Ms. Emma Nyaola</td>
<td>KALRO</td>
<td><a href="mailto:emma.nyaola@kalro.org">emma.nyaola@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Henry Wanyama</td>
<td>KALRO</td>
<td><a href="mailto:henry.wanyama@kalro.org">henry.wanyama@kalro.org</a></td>
</tr>
<tr>
<td>Ms. Carolyne Minayo</td>
<td>KALRO</td>
<td><a href="mailto:carolywn.minayo@kalro.org">carolywn.minayo@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Nathan Maweau</td>
<td>KALRO</td>
<td><a href="mailto:nathan.maweau@kalro.org">nathan.maweau@kalro.org</a></td>
</tr>
<tr>
<td>Mr. Rophin Nyange</td>
<td>SDL</td>
<td><a href="mailto:nyangerk@yahoo.com">nyangerk@yahoo.com</a></td>
</tr>
<tr>
<td>Mr. Ernest Mbogo</td>
<td>SDL</td>
<td><a href="mailto:ernestmbogo@gmail.com">ernestmbogo@gmail.com</a></td>
</tr>
</tbody>
</table>
IGC-IRC REVIEWERS

Albert
Aldo
An
Andras
Andre
Andrew
Ann
Azizza
Babo
Bernard
Bockline Omedo
Bossima Ivan
Boval
Bruce
Bulgamaa
Carol
Caroline
Charles
Dan
Dana
David
David
David Duba
David Layne
Dereje
Dildora
Douglas
Douglas
Edwin
Elisa
Elisabeth
Elkana
Fabiana
Fava
Fernando
Fernando
Fiona
Francis
Gabriel
Gautam
Gordon
Hajime
Helen
Hussein Tadicha
Irenie
James
Jane
Jane
Craig
Sales
Notenbaert
Halasz
Sbrissia
Williams
Waters-Bayer
Mala
Fadalla
HUBERT
Bebe
Koura
Maryline
Pengelly
Densambuu
Kerven
Wambui
Gachuiri
Brockington
Kelly
BRISKE
Kemp
Mwangi
Golicha
Coppock
Wakjira
Aralova
Johnson
Indetie
Wolfe
Oteros-Rozas
Huber-Sannwald
Nyambati
Villa Alves
Francesco
Quadros
Ortega-Klose
Flintan
Muyekho
Oliva
Sarath
Jones
Kumagai
Sheridan
Wario
Chakoma
O‘Rourke
Addison
Wamuongo
Jay
Jean-Hugues
Jesse
Joanne
Jones
Jose
Joyce
Julius Pyton
Kannan
Karma
Katherine
Kenneth
Lan
Lance
Li
Liz
Mansour
Maria
Maryam
Mary-Jane
Meredith
Michael
Michael
Mohammad
Mohammed
Mohammed Sghir
Monica
Moses
Nagaratna
Nanak
Neil
Newton
Niall
Nicholas
Oliver
Oscar Kipchirchir
Otsanjugu Aku Timothy
Pablo
Pankaj
PETER
Robert
Robin
Rogerio
Rupsha
Sebastiao
Shin-ichiro
SITA
Solomon
Angerer
Hatier
Njoka
Millar
Chris Stephen
Dubeux
Maina
Sserumaga
Dorai Pandian
Tenzing
Homewood
Quesenberry
Xu
Robinson
Li
Wedderburn
Mesdaghi
Fernandez-Gimenez
Niamir-Fuller
Rogers
Mitchell
Peters
Hare
Farzam
Abdelkreim
TALEB
Sacido
Nyangito
Biradar
Pasricha
Cliffe
Lupwayi
Hanan
Ellison
Wasonga
Koech
Namo
Manzano
Joshi
DELE
Dixon
Reid
Mauricio
Banerjee
Mahunguane
Ogura
GHIMIRE
Mwendia
<table>
<thead>
<tr>
<th>Name</th>
<th>Last Name</th>
<th>Name</th>
<th>Last Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steven</td>
<td>Bray</td>
<td>Sultan</td>
<td>Singh</td>
</tr>
<tr>
<td>Susana</td>
<td>Feldman</td>
<td>Tabby</td>
<td>Karanja-Lumumba</td>
</tr>
<tr>
<td>Temesgen Jembere</td>
<td>Bakara</td>
<td>Tersur Theophilus</td>
<td>Akpensuen</td>
</tr>
<tr>
<td>Thomas</td>
<td>Groen</td>
<td>Vincent</td>
<td>BLANFORT</td>
</tr>
<tr>
<td>Tungalag</td>
<td>Ulambayar</td>
<td>Walter</td>
<td>Ayala</td>
</tr>
<tr>
<td>Vanessa</td>
<td>Olson</td>
<td>Wilfred</td>
<td>Odadi</td>
</tr>
<tr>
<td>Victor</td>
<td>Kamadi</td>
<td>William</td>
<td>Anderson</td>
</tr>
<tr>
<td>Yanqi</td>
<td>Wu</td>
<td>YASUYUKI</td>
<td>ISHII</td>
</tr>
<tr>
<td>Zhibiao</td>
<td>Nan</td>
<td>Yingjun</td>
<td>Zhang</td>
</tr>
</tbody>
</table>
TABLE OF CONTENT

PREFACE ........................................................................................................................................ v
KEY MESSAGES/ OUTPUTS ........................................................................................................ vii
ACKNOWLEDGEMENT .............................................................................................................. ix
OPENING SPEECHES ................................................................................................................ x
SPEECH BY THE HON. PETER G. MUNYA, CABINET SECRETARY, MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVE (KENYA) ................... xi
OPENING REMARKS BY PROF. HAMADI BOGA, EBS, CGH, PRINCIPAL SECRETARY (PS), STATE DEPARTMENT FOR CROP DEVELOPMENT AND AGRICULTURAL RESEARCH, MINISTRY OF AGRICULTURE, LIVESTOCK FISHERIES AND COOPERATIVES, NAIROBI, KENYA ................................................................. xiv
OPENING SPEECH BY DANA KELLY, PRESIDENT OF THE INTERNATIONAL RANGELANDS CONTINUING COMMITTEE ................................................................. xvi

The IGC Business meeting minutes .......................................................................................... xviii
The IRC Business meeting minutes ........................................................................................... xxiii
IGC Summary Paper ..................................................................................................................... xxxvii
IRC Summary Paper ................................................................................................................ x1
Membership of the National Organizing Committee of the Joint IGC-IRC Nairobi 2021 ........ x1v
IGC -IRC REVIEWERS .............................................................................................................. x1vi

CONCURRENT SESSION 1 ............................................................................................................ 1
THEME 1. RANGE/GRASSLAND ECOLOGY ............................................................................. 1

Topic: Remote sensing, risk analysis and land management ............................................................. 1
Development of models for simulation of available forage Biomass in the native vegetation of the Brazilian semiarid through remote sensing Candido, M.J.D; Morais, L.F; Cavalcante, A.C; Costa, F.O............................................................. 7
Lowveld savanna bush cutting alters tree-grass interactions Wedel, ER; Nippert JB; Swemmer AM.. 10
Multifunctionality of sown grassland is enhanced by combining four complementary species Suter, M.; Huguenin-Elie, O.; Lüscher, A............................................................. 15
Effects of herding on rangeland use efficiency in Kenya Seidel, A.; Asch, F.; Warth, B. ..................... 20

THEME 2: FORAGE PRODUCTION AND UTILIZATION ............................................................. 25

Topic: Temperate/Tropical Transition Climate Zones: Locations for Breeding Forages with Climate Resiliency .............................................................................................................. 25
Temperate/tropical transition zones: a hotspot for breeding forages with climate resiliency Quesenberry, K. H.; Rios, E. F.; and Kenworthy, K. E............................................................. 26
Breeding forage annual ryegrass at the University of Florida Kenworthy, K.E., Reith1, P.E., Rios, E.F, Blount, A.R., van Santen1 E. and Quesenberry, K.H........................................................................ 32
Moving warm-season forage bermudagrass (Cynodon sp.) into temperate regions of North America Anderson, W.F.; Baxter, L.; Hancock, D.; Gates, R.N.; Rios, E.F............................................................. 37
Breeding perennial warm-season grasses for the subtropical belt in South America Acuña, C.A......41
Warm-season legumes – Challenges and constraints to adapting warm-season legumes to transition zone climates with examples from Arachis Assis, GML1; Dubeux Jr., JCB .........................................46

THEME: 2 FORAGE PRODUCTION AND UTILIZATION..........................................................51

Topic: Recent advances in Urochloa grass research in Kenya..................................................51

Productivity and nutritive value of Urochloa grass cultivars in semi-arid tropical Kenya  Njarui, D.M.G.1. and Gatheru, M.......................................................61

THEME 3: LIVESTOCK PRODUCTION SYSTEMS....................................................................70

Topic: Beef and Dairy Production Systems............................................................................70

Management strategies for enhanced beef production on suckler cow farms  Asheim, L.J.; Aass, L.; Åby, B.............................................................................................................71
Progardes® Desmanthus: good for beef, good for the environment Gardiner, C, Mwangi, F, Charmley, E, Hall, T, Suybeng, B, Walker, G.................................................................76
Bee-friendly beef: developing biodiverse pastures to increase ecosystem services  Wagner, J.; Ghajar, S., O’Rourke, M., Tracy, B.........................................................................................80
What are the main limits to smallholder livestock production in the tropics – according to farmers? Duncan, A.J.....................................................................................................................85

THEME 4: WILDLIFE AND MULTI-FACETS OF RANGELAND/GRASSLAND.........................89

Topic: Biodiversity, Ecosystem services and Ranching..............................................................89

Brazilian Pampa rangelands: challenges in the face of soybean expansion................................90
The new tendencies of environmental impact assessment of livestock production: a road testing of LEAP/FAO Biodiversity Assessment Guidelines in pastoral systems in Uruguay  de Santiago, F., Pompozzi, G., Simó, M., Blumetto, O................................................................................95

THEME 5. DROUGHT MANAGEMENT AND CLIMATE CHANGE IN RANGELANDS / GRASSLANDS.................................................................105

Topic: Land use, Carbon Sequestration and GHG fluxes..........................................................105

Exploring water use and production dynamics of indigenous protected Sikumi forest in south western Zimbabwe  Gwate, O.......................................................................................................106
Long-term N addition, not warming, increases net ecosystem CO2 exchange in a desert steppe in northern China  Han, G.; and Wu, Qian................................................................................111
Quantifying greenhouse gas emissions attributable to smallholder livestock systems in Western Kenya: cradle to farm gate life cycle assessment  Ndung’u, P.W., Takahashi, T., du Toit, C.J.L., Robertson-Dean, M., Butterbach-Bahl, K., McAuliffe, G., Merbold, L.2., Goopy, J.P........................................116

THEME 6. PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES......................................123
Topic: Changes in rangeland property rights and land use in Central Asia and Western China...123
The role of community cooperative institutions in addressing livelihood challenges in the process
urbanization of pastoral regions in China Gongbu, Z. and Zhang, Z.............................................................................130
Obstacles to the revival of mobile grazing systems in Kazakhstan Robinson, S., Bozayeva, J., Mukhamedova, N., Djanibekov, N., Oshakbayev, D., Petrick, M.........................................................135

THEME 7: CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE
DEVELOPMENT IN RANGELANDS/GRASSLANDS........................................140

Topic; Participatory socio-ecological observatories for sustainable rangeland development...140
Drylands Participatory Observatories: a new socio-ecological technology to co-produce knowledge
and science to develop policies for sustainable development Martinez-Tagüeña, N, Huber-Sannwald,
Long-term socio-ecological research in the Biosphere Reserve in Mapimi, Mexico: a multidimensional
participatory observatory of rangeland/pastoral systems Reyes Gómez, V.M.1; Huber-Sannwald, E.,
Martinez Tagüeña, N., Espejel Carvajal, I., Lucatello, S., Bowker, M.A., Lauterio Martinez, C.L.146
A network of transdisciplinary observation mechanisms as a digital source of knowledge on
rangeland, to communicate and exchange at local, regional and global scales Rizzo, A.; El Mahdad,
E., Sifeddine, A., Lucatello, S., Bouchaou, L., Huber-Sannwald, E. .........................................................151
Participatory management of rangeland hydrology – a new socio-ecological technology to effectively
adapt to and mitigate climate change: case from Morocco Bouchaou, L., Lhssaisoune, M., El Hassan
Beraaouz1, Sifeddine, A., Rizzo, A, Hssaisoune, M1, Reddad, H, Chehbouni, A., Huber-Sannwald, E.
................................................................................................................................................................156

KEYNOTE 1 Exploring the information base needed for sustainable management of rangeland
resources for improved livelihoods Johnsen, K.I.; Niamir-Fuller, M.; Bensada, A; Waters-Bayer, A....
..........................................................................................................................................................160
KEYNOTE 2 ASustainable use of Grassland Resources for Improved Livelihoods Liana Jank,
Cacilda Borges do Valle, Rosangela Maria Simeão, Roberto Giolo de Almeida, Mateus Figueiredo
Santos, Sanzio Carvalho Barrios.....................................................................................................................165
THEME KEYNOTE 1:Capacity, Institutions and Innovations for sustainable development in
Rangelands/Grasslands Dr Jonathan Davies, IUCN.................................................................................177

CONCURRENT SESSION 2..........................................................................................................................178
THEME 2: RANGE/GRASSLAND ECOLOGY..................................................................................178

Topic: Rangeland monitoring and support systems.................................................................178
Positive changes in regional vegetation cover in Patagonia shown by MARAS monitoring system
Oliva, G. El1 and J. Gaitan......................................................................................................................179
EcoRestore: Decision Support System to restore the productivity of degraded rangelands in southern
Africa Kellner, K., Pretorius, D. and Marais, C..............................................................183
Enhanced grazing management assessment using drone-based lidar measurements Temu, V.W.;
Hession, W.C.; Sforza, P.; Wang, H..............................................................................................................187

THEME 1: RANGE/GRASSLAND ECOLOGY........................................................................191

Topic: Rangeland degradation and restoration .................................................................191
C3 perennial grass dominates mixed C3/C4 grasslands after invasion by a C3 woody sprouter Cooper,
C.E.,Ansley, R.J.,Steffens, T.J., Murray, D.B., Zhang, T.................................................................192
Characterization of degree of Eco-restoration by tree-grass interaction in degraded lands of Semi-
arid Tropics Kumar RV; Ghosh A, Singh A.K., Kumar Sunil, Roy AK., Gautam Kamini............197
Counteracting green alder shrub expansion by low-input grazing Schneider M.K.; Zehnder T.; Berard; Pauler C.; Staudinger M.; Kreuzer M. and Lüscher A.................................................................200

Rangeland management in a changing world – active and passive restoration case studies from Ethiopia, Tanzania, and South Africa Treydte, A.C.; Baumgartner, S.A.; Tuffa, S.K.; Abdeta, A. A.. .................................................................................................................................205

Rejuvenation of rangelands – role of diversity and improvement strategies of range grasses...........208

**THEME 2: FORAGE PRODUCTION AND UTILIZATION**.................................................................................................212

**Topic: Forage genetics and improvement**..........................................................................................................................212

Identification and analysis of flowering time candidate genes of *Dactylis glomerata* L. Zhang, X.Q; Feng, G.Y; Huang, L.K; Zhao; Yang, Z.F.................................................................................................................................213


Identifying forage quality Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] genotypes from a wild regional collection Hollowell, D.M.; Morrison, J.I.; Baldwin, B.S.................................................................223

**THEME 3: LIVESTOCK PRODUCTION SYSTEMS**..................................................................................................................226

**Topic: Social-Economics of livestock production systems**..........................................................................................................................226

Involving stakeholders in crop-livestock systems analysis: Innovation Platforms in Burkina Faso and Niger, West Africa.................................................................227

Food security in crop, livestock and mixed farming systems in Mali.................................................................232

Why We Need a Ruminant Revolution: Combating Malnutrition and Metabolic Illnesses to Enable Sustainable Development.................................................................237

Analysis of Actors and Activities at Dagoretti Livestock Market in Nairobi City, Kenya........242

**THEME 2: FORAGE PRODUCTION AND UTILIZATION**.................................................................................................248

**Forages and Environment Improvement**..........................................................................................................................248

Nutrient return from plant litter and cattle excretion grazing on N-fertilized grass or grass-legume pastures in North Florida Garcia, L.; Jaramillo D.M.; DuBeaux Jr, J.C.B.; Sollenberger, L.E.; Vendramini, J.M.B.; DiLorenzo, N; Santos, E.R.S; Ruiz-Moreno, M; Queiroz, L.M.D........249

KThe morphological, crude protein and *in-vitro* dry matter degradability characterisation of nine native grass species for veld restoration in semi-arid environment Msiza, NH; Ravuhali, KE ; Mokoboki, HK ; Sydney Mavengahama, .................................................................253

Grass-legume mixtures for diversified and profitable forage production Islam, M.A.; Ashilenje, D................................................259

**THEME 7: CAPACITY, INSTITUTION AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS**.................................................................................................264

**Topic: Management, land use planning and ecosystem services**.................................................................................................264

Water use efficiency and land cover variability on a native grassland ranch on the pampa biome of Uruguay Restrepo-Osorio, Diana. L; De Oliveira, G; Coll, J; Schossler, D.................................................................265

Revisiting the concept of the planning region in settings with dynamic spatial-temporal conditions: Lessons from land use planning in pastoral areas of Kenya, Ethiopia and Tanzania Musoga, H.; Robinson, L.W........270

Adaptive, multi-paddock, rotational grazing management: An experimental, ranch-scale assessment of effects on multiple ecosystem services Augustine, D.J.; Derner, J.D.; Poresky, L.M.; Wilmer, H.; Fernández-Giménez, M.; Briske, D.D.................................................................274
Scalable online scenario development tool for rangeland conservancy managers using high spatial-temporal resolution carrying capacity maps and livestock market data  Boerboom, L.G.J.; Ohuru, R.O.; Toxopeus, A.G.; Nieuwenhuis, W.; De Bie, C.A.J.M; Mwangi, P.K.; Schouwenburg, M.L.; Lemmens, R.L.G........................................................................................................................................................279

Assessing the impacts of different initiatives on the rehabilitation of pastoral and silvopastoral ecosystems: Big Data oriented approach  Moukrim S., Lahssini S., Naggar M., Menzou K., Mharzi-Alaoui H., Labbaci A., Rhazi L..................................................................................................................................................284

CONCURRENT SESSION 3 ........................................................................................................................................288

THEME 1: RANGE/GRASSLAND ECOLOGY ........................................................................................................288

Topic: Sustainable land use .................................................................................................................................262

Grólind – Sustainable Land use Based on Ecological Knowledge  Marteinsdóttir, B1; Þórarinsdóttir E.F.; Halldórrsson G.; Stefánsson J.H.; Bórsson J.; Sævarsdóttir K.; Finnsdóttir R.; Þórðsdóttir S. ........................................................................................................................................293

Holistic planned grazing can improve vegetation attributes of the semi-arid communal rangelands of the Lowveld in the Eastern Cape, South Africa  Mudyiwa, S.M.; Beyene, S.T.; Mopipi, Kth........................................297


Pre- and Post-Degradation Management of Rangelands: Implications for Sustainable Management  Tuffa S.; Treydte, A. C..............................................................................................................................................................305

THEME 2: FORAGE PRODUCTION AND UTILIZATION ........................................................................................310

Topic: Forage evaluation & agronomy ................................................................................................................310

Induction of tetraploid ruzigrass (Brachiaria ruziziensis) by colchicine and possibility of using seed weight as screening method  Poungkaew, R.; Mangpung, Y.; Arananant, J.; Chuchuay, P.; Thaihua, S.; Chanpeng, P.................................................................................................................................................................................................311

Differences in Urochloa hybrids and cultivars biomass production in several sites in western Kenya  Mwendia, S.W.; Notenbaert, A.O.; Mwangi, D.M.; Odhiambo, R.; Guto, I.; Juma, A..........................................................................................................................317

Formononetin of Red Clover (Trifolium pratense L.) as affected by water availability  Ortega-Klose, F.; López-Olivari, R.; Melo, M.; Quiroz, A.; Bardehle, L.................................................................322

Evaluation of yields and nutritive composition of dual purpose sweet potato vine cultivars for forage use  Kenana, R.S.; Hoka, A.I.; Ondabu, N.; Ondabu, F.; Mercy, J.......................................................................................................................................................................................326

THEME 2: FORAGE PRODUCTION AND UTILIZATION ........................................................................................331

Topic: Forage legume ecosystem services in sustainable livestock systems................................................................331

Forage legumes in tropical regions: recent advances and future challenges  Casagrande, D.R.1; Homem, B.G.C.; Boddey, R.M..................................................................................................................332


The importance of forage legume inclusion in agricultural swards to enhance earthworm activity and water infiltration rates  Shnel, A; Tracy, S; Schmidt, O; Murphy, P; Lynch, M.B; Grace, C; Boland, T.M; Sheridan, H........................................................................................................................................341

Tree legumes as sustainable ecosystem services in livestock systems  Muir, J.P.; Cooper, C.E., Corriher-Olson, V....................................................................................................................................................................................346

THEME 3. LIVESTOCK PRODUCTION SYSTEMS .................................................................356
Sustainable management of grasslands/rangelands ecosystems ........................................356
   Short-term high-performance pastures in temperate eastern Australia ..........................357
   A systematic review of ecological and production outcomes under rest-grazing systems .................................363
   Restoring value to grassland initiative: to maintain the environmental and economic value of grasslands and to promote their social and cultural functions  Wedderburn, L; Ickowicz, A; Mauricio, R.M; Quiroga Mendiola, M; Blanchard, M; Le Thi Thanh Huyen; Hubert, B; Lasseur, J; Blanfort, V; Müller, J-P .................................................................368
   Revisiting the reciprocity of human-ecological systems: Integrating extensive agriculture and transhumant pastoralism in the Northern states of India ........................................372
THEME 5- DROUGHT MANAGEMENT AND CLIMATE CHANGE IN RANGELAND/GRASSLANDS .........................................................378
Topic: Droughts and degradation – social ecological perspectives on tipping points in dryland rangelands .......................................................................................................................378
   Rangeland management in Namibia in the face of looming desertification: Insights from the freehold farmers’ perspective Brinkmann, K.; Liehr, S.1.; Lena Bickel ..........................................................379
   Strategies for assessing grassland degradation with biogeochemical models  Rolinski, S.; Wirth, S.B.; Müller, C.; Tietjen, B ........................................................................................................383
   Stakeholder attitudes towards wildlife-based land use in Namibia’s Kunene Region Luetkemeier, R. ; Kraus, R.; Mbidzo, M.; Hauptfleisch, M.; Liehr, L .................................................................................388
   Towards early warning signals for desertification  Klingenberg, Sara; Heshmati, Sara; Ruppert, Jan C.; Tielbörger, Katja .....................................................................................................................393
THEME 6 – PASTORALISM, SOCIAL AND POLICY ISSUES ............................398
Topic: International Year of Rangelands and Pastoralists, Part 1 Panel 1 and 2 ...........398
   International Year of Rangelands and Pastoralists (IYRP) History, Process, Priority Themes and Way Forward James T. O’Rourke1; Maryam Niamir-Fuller; Barbara Hutchinson ...........................................399
   Priority Areas for Action and Research on Pastoralism and Rangelands in Eastern Africa Odhiambo, M.O ..................................................................................................................406
   Rangelands and pastoralism in Central Asia and Mongolia: challenges and perspectives Ulambayar, T .................................................................................................................................410
Panel 2: Topic: Socio/economics and demography .........................................................415
   Rangelands and pastoralism of the Middle-East and North Africa, from reality to dream Naghizadeh, N; Badripour, H; Louhaichi, M; Gamoun, M; and Niamir Fuller, M ......................................................................................416
   Action Plan for the International Year of Rangelands and Pastoralists (IYRP): The Case for the United States, Canada and Mexico Barry Irving,; Larry Howery,; Jürgen Hoth,; Jess Peterson .............................................................................421
THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES ........427
Topic: Local knowledge, local and global action ............................................................427
   Valuing the expertise of mobile herders in arid South Africa- a photographic essay Cupido, C.F; Ellis, W. ; Samuels, M ..........................................................................................................................428
   Pastoral traditional ecological knowledge dynamicity: a global review Sharifian Bahraman, A; Fernández-Llamazares, Á; Wario, H; Molnár, Z; Cabeza, M .........................................................................................432
   Transdisciplinary research in practice: lessons from participatory, folklore and community-supported approaches in the greater American West Wilmer, H.; Carr Childers, L.; Porensky, L.M ........................................................................437
Shift in management strategy of yak herding in the south of Mustang District, Nepal, Himalaya. 442
Women and their children in charge of management decisions of a communal range Trejo-Arista, L. K.; Martínez-Hernández, P. A.; Cortés-Diaz.; E. Posgrado en Producción Animal, Universidad Autónoma Chapingo, Chapingo, México. 447

KEY NOTES .......................................................................................................................... 451

THEME KEYNOTE 2........................................................................................................... 452

Forage production for improved on-farm wealth and wellness Caradus, J. .................................. 452

THEME KEYNOTE 3.......................................................................................................... 462

Ruminant livestock production systems and imperatives for sustainable development Smith, J. 462

THEME KEYNOTE 4.......................................................................................................... 467


CONCURRENT SESSION 4 ............................................................................................... 475

THEME 1- RANGE/GRASSLAND ECOLOGY ...................................................................... 475

Topic: Grazing, soil nutrient and properties ........................................................................... 475

Carbon and nitrogen pools in soil aggregates were affected by grazing component ---- results from dry and wet sieving methods Liu, N; Wei, Y.Q; Pang, Y; Wei, B; Zhang, Y.J. .................................. 476

Influence of seasonality and agricultural practices on soil microbes in Kamishiho, Japan Madegwa, Y; Uchida, Y............................................................................................................................................. 480

Soil carbon stocks are stable under New Zealand hill country pastures with contrasting phosphorus and sheep stocking regimes Vibart, R.; Mackay, A.D.; McKenzie, C.; Devantier, B.; Costall, D.; Noakes, E.; Bilotto, F. ........................................................................................................................................... 484

THEME 1. RANGE/GRASSLAND ECOLOGY ...................................................................... 489

Topic: Communit composition and ecological drivers .......................................................... 489

Climate variability in the Woodbush Granite Grasslands of South Africa: Effects on grassland diversity........................................................................................................................................... 490

Mongolian rangelands have a great potential for natural recovery Bulgamaa, D.; Sumjidmaa, S.; Brandon, B., Budbaatar, U., Burmaa, D., Erdenetsetseg, B. ........................................................................................................................................... 496

Germinable soil seed bank of Bothriochloa macra dominated pasture in south-eastern Australia Mitchell, M.L.; Virgona, J.M.; Durling, A.; Dempsey, F.W. ........................................................................................................................................... 500

Effects of Parthenium hysterophorus on grassland community in Nyando Sub-county, Kisumu County, Kenya Mutua, B. M; Chiuri, W. ................................................................................................................................................ 505

THEME 2. FORAGE PRODUCTION AND UTILIZATION ..................................................... 509

Topic: Tropical Forage Genetic Resources ........................................................................... 509

Forage Genetic Resources in Brazil Jank, L.; Santos, M.F.; Valle, C.B. do; Barrios, S.C.; Simeão, R. M. ........................................................................................................................................... 510

Future generations – will any be lacking tropical forage genetic resources? Maass, B.L.; Pengelly, B.C. ........................................................................................................................................... 513

Rebuilding a tropical forages for the future network – a call for resuscitating enthusiasm for a commodity with great prospects and innovation potential Pengelly, B.C.; Maass, B.L. ........................................................................................................................................... 518

Linking demand with supply for tropical forage genetic resources to reach impact at scale Peters, M; Burkart, S; Ohmstedt, U; Castiblanco, C; Stern, E; Nicolayevsky, A; Enciso, K; Diaz, M; Mwendia, S; Douxchamps, S; Notenbaert; Lukuyu, B.; Fuglie, K. ........................................................................................................................................... 523
**THEME 3. LIVESTOCK PRODUCTION SYSTEMS**

**Topic: Small ruminant production systems**

Ewe daily-weight gain grazing *Leucaena leucocephala-Megathyrsus maximus* CV Mombasa silvopastoral system and tropical native unimproved range Trejo-Arista, L. K; Cortés-Díaz, E.; Martínez-Hernández, P. A.; Cadena-Meneses, J. A. ...............................................................529

Impact of fescue toxicosis on fetal development and postnatal growth Duckett, S. K.; Greene, M. A.; Britt, J. L.; Andrae, J. G. ...............................................................................................................533

Simulation of alternative plans for community based goat breeding program in arid, semi-arid and mixed production systems in Ethiopia Jembere, T.; Rischkowsky, B; Dessie, T; Kebede, K; Okeyo Mwai, A; Mirkena, T; Haile, A.................................................................537

**THEME 6: PASTORALISM, SOCIAL GENDER AND POLICY ISSUES**

**Topic: Governance, Investment, Infrastructure and Markets**

Perceptions on governance for effective adaptation to climate change within community-based wildlife conservancies in Kenya Kibet, S. and Wasonga, O.V. ........................................................................543

Climate Change Policy Narratives and Pastoralist Predicaments in the Horn of Africa: Insights from Ethiopia and Kenya Campbell, T. ........................................................................................................550

Large scale land investments and food security in agro-pastoral areas of Ethiopia Bekele, A.E., Dries, L.; Heijman, W and Drabik, D. 2 ........................................................................................................555

Exploring institutional complementarity and social thresholds of mobility in pastoral social-ecological systems in Mongolia Kasymov, U.; Ring, I. .................................................................................................558

**THEME 6. PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES**

**Panel 3 Topic: Climate change and ecosystem health**

Action Plan for the International Year of Rangelands and Pastoralists (IYRP): The Case for Mexico Huber-Sannwald, E. .......................................................................................................................564

Challenges of pastoralism and rangelands in Europe Manzano, P .................................................569

**THEME 7. CAPACITY, INSTITUTION AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS**

**Topic: Participatory monitoring and silvopastoral systems**

Silvopastoral strategy and sustainable management of forests in Morocco Mustapha, N; Said, L; Said, M and Anass, L...........................................................................................................................................576

Status, management, and governance of the communal grasslands of Ethiopia’s highlands: a disappearing asset for mixed crop-livestock livelihood systems Bedasa, E.; Fiona, F.; Tesfa, G and Jason, S...........................................................................................................................................579

Land Users – Land Watchers Stefánsson, J.H. & Marteinsdóttir, B......................................................................................................................586

The role of indigenous knowledge in the effective collective management of the communal rangelands Finea, A.; Linnane, S.; Getty, D; Slinger, J.H.................................................................................................................................589

**CONCURRENT SESSION 5**

**THEME 1: RANGE/GRASSLAND ECOLOGY**

**Topic: Ecohydrology and plant responses**

Effects of thinning density on soil water content of alfalfa and David peach intercropping in the hilly Loess Plateau, China Chen Z.X.; Yang X.L.; Wang G.H.; Shen Y.Y. ......................................................................................................................595

Plant root mass fraction response to soil resource limitation in the context of dry Mediterranean rangeland Dovrat, G. ...........................................................................................................................................598
Rangeland rehydration: collaboration between land managers, government and private experts Theakston, P.; Pringle, H.J.R; Mashford, L.................................................................601
Woody plant species composition and diversity in Rusinga Island, Homa Bay County, Kenya Nyaga, M. N; Mureithi, S. M; Wasonga, V. O; Koech, O. K.................................................................606

THEME 1: RANGE/GRAASSLAND ECOLOGY........................................................................610

Topic: Fire ecology, plant responses and management..................................................610
Hydraulic responses of shrubs and grasses to fire frequency and drought in a tallgrass prairie experiencing bush encroachment O’Keefe, K; Keen, R; Tooley, E; Bachle, S; Nippert, JB; McCulloh, K.................................................611
Prescribed fire plus grazing horses: A sustainable model to decrease fire hazard in a mountain landscape Torres-manso, F.; Pinto, R.; martia-costa, A.; Fernandes, P.; Fernandes, M. .................616
Modelling burning and grazing in communal rangelands to help understand trade-offs between production, carbon, and water Hawkins, H-J; Moradzadeh, M; Vermeire, M-L; Farai Chikomba; Wu, L........................................................................................................................................620

THEME 2: FORAGE PRODUCTION AND UTILIZATION......................................................625

Topic: Water Stress & Water Use Efficiency......................................................................625
Effect of drought stress on fibre digestibility of corn for silage Ferreira, G.; Teets, C.L.; Kingori, A.M.; Ondiek, J.O........................................................................................................626
The effect of water deficits during flowering and seed production on cultivars of subterranean clover and annual medic Wolfe, E.C (Ted); Collins, W.J.; Rossiter RC.; Sterm WR .................................................630
The response of selected temperate forages to increasing summer drought conditions and high summer temperatures in northern Victoria, Australia Rogers, M. E., Lawson, A. R.; Kelly, K. B.; Wales, W. J. and Jacobs, J. L.................................................................636
Sowing rate effects on biomass production of a forage oat in the Qinghai-Tibetan Plateau Liu, C.T.; Zhang, H.B.; Deng, J.Q.; Shen, Y.Y........................................................................................................641
Irrigation management strategies for fodder beet (Beta vulgaris L.) crops Khaembah, E. N.; de Ruiter, J. M.; Chakhwiza, E.; Maley, S. and George, M.J.................................................................645

THEME 3: LIVESTOCK PRODUCTION SYSTEMS..................................................................649

Topic: Challenges on livestock production and rangelands/grasslands utilization in southern South Africa.................................................................649
Sustainable intensification in crop-livestock systems Rovira, P; Carvalho, P.C.F., Terra, J., Lattanzi, F., Pizio, R, Ayala, W.................................................................650
The importance of Campos ecosystem as a world food producer and as a provider of ecosystem services.................................................................655
Using perennial rangeland grasses for bioenergy and cattle grazing Feldman, S.R.; Sacido, M.B.; Jozami, E.; Castagnani, L.................................................................661

THEME 5: DROUGHT MANAGEMENT AND CLIMATE IN RANGELANDS/GRAASSLANDS.................................................................................................665

Topic: Climate change impacts and mitigation.................................................................665
Differential effects of changed precipitation patterns on co-existing dominant species in Inner Mongolia typical grassland: significance for drought management Zhou, S-X12; Wu, D-X11........666
Risk of climate-related impacts on global rangelands – a review and modelling study Godde, C.M., Boone, R.B., Ash, A., Waha, K., Sloat, L., Thornton, P., Mason-D’Croz1, D., Mayberry1, D., Herrero, M.................................................................671
Visual assessment of soil structure as an early indicator of soil quality in response to intensive rotational grazing  Teutscherova, N; Vazquez, E; Baquero, D; Velasquez-Ruiz, NE; Pulleman, M; Arango, J.................................................................................................................................675

Interventions for mitigating drought-related livestock mortality in Africa’s pastoral areas: a review of their relevance and effectiveness with special reference to Kenya Dabasso, B. H............................................................................680

Uses and knowledge of plant species by mongolian herders in the gobi desert and identification of species of interest for planting Barnes, A.J.; Taugourdeau, S.; Bazan, S; Rayot, V; Enkhjargal Ts............................................................687

THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES.............................692

Topic: Developing environmental services payments schemes for grassland in China and Mongolia ...........................................................................................................................................692

Management changes and strategies to improve the environmental services from grasslands in northern China and Mongolia Kemp, D.R; Addison, J; Behrendt, K; Udval, G; Lkhagvaa, D; Han, GD; Li ZG; Li P.................................................................................................................693

The state of grasslands across Inner Mongolia and Mongolia Guodong Han, G.; David Kemp; Bulgamaa Densambuu; Zhiguo Li, Cuiping Gao, Zhongwu Wang; Zhiqiang Qu; Mengli Zhao, Udval G; Qian Wu; Naya and Linxi Hu..............................................................................................698

Herders’ attitude and decision making in stocking rates and implication for grassland management in China Li Ping, Zhi Rong, Jeff Bennett, Lin Kejian, Jin Ke........................................................................................................703

Implications of herder attitudes for stocking rates in China and Mongolia Yin Yanting, Li Ping, David Kemp........................................................................................................................................708

Modelling the long-term impact on herder incomes and environmental services in an uncertain world Behrendt, K.; Kemp, D.R.; Udval, G.; Jargalsaihan, G.; Han, G.D.; Li Z.G.; Li, P.; Lkhagvaa, D........................................713

THEME 7. CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS..............................................718

Topic: Accelerating the use of participatory action research for development in pastoral lands: challenges and opportunities..............................................................718

Co-produced research supports pastoralists to pursue transformative social and ecological change in rangelands Reid, R.S., Kassam, K.A.S.; Pickering, T.; Yasin, A.; Jamsranjav, C., Jamiiyansharav, K., Ulambayar, T. and Knapp, C.N.............................................................................................................719

Engaged Research Can Advance Knowledge AND Promote Positive Change Among the Rural Poor Coppock, D. L............................................................723


Producing useful knowledge for sustainable development Galvin, K.A........................................................734

THEME 3: LIVESTOCK PRODUCTION SYSTEMS..................................................................738

Topic: Climate change; adaptations and resilience of Livestock systems................................................738


Understanding the effects of a tannin extract on forage protein digestion in the rumen and abomasum using a dynamic artificial digestive system coupled to a digestomic approach  Sayd, T.; Chambon, C.; Torrent; A.; Blinet, S.; Theron, L. and Niderkorn, V. ................................................................. 755

KEYNOTES ........................................................................................................................................... 760

THEME KEYNOTE 5 .................................................................................................................................. 760

Drought management and climate change in rangelands and grasslands .............................................. 760

THEME KEYNOTE 6 .................................................................................................................................. 761

Biodiversity conservation and sustainable livelihoods in rangelands: Trends, challenges and opportunities John Waithaka .................................................................................................................. 761

THEME KEYNOTE 7 .................................................................................................................................. 766

Pastoralism, social, gender and policy issues Nahid Naghizadeh, Member of the Board, CENESTA, Iran ...................................................................................................................................................... 766

CONCURRENT SESSION 6 ......................................................................................................................... 771

THEME 1: RANGE/GRASSLAND ECOLOGY ................................................................................................. 771

Topic: Commons: old, current and future challenge for rangeland what innovations in collective issues to face these challenges ........................................................................................................................................ 771

Collaborative construction of a method that contributes to improve the decision making in associative ranches by controlling the grass allowance in a context of climate variability Emilio Duarte Esteves Romulo Cesar, Javier Fernández 1, Marcelo Ghelfi 1, Valentina Herrera 1, Virginia Caravia, Rodrigo Irbarne, Federico de Brum, Héctor Rodríguez, Marcelo Pereira Machín .................................................................................................................. 772

Collective Approach of Rural Development: Case Study of “Maronna Foundation” in the Pampa Bioma, Rio Grande do Sul, Brazil............................................................................................................... 776

Identifying land use options for networked Māori owned land blocks to deliver on collective aspirations in New Zealand McCrossin, N; Walker, F A; Wedderburn, M.E.; Mato, R; McMillan, W ................................................................ 680

Rangeland in Marajó Island, Brazilian Amazon, a Long History of Commons for Small-Breeders Barbosa, T.,1 Oppler, M.,1,2 Folhes, R.,3 Carvalho, S.,4 Tourrand, J. F,5 ................................................................................ 784

Livestock policy in Special Areas, Alberta, Canada Strankman, P.L. .......................................................... 787

Intensive Poultry Production as a “Collective” Initiative to Face Global Change in the Bedouin Area of the North Western Coast Zone (NWCZ), Egypt Daoud, I.1, Osman, M.A.2, Alary, V.3, Tourrand, J.F.4 .................................................................................................................. 791

THEME 2. FORAGE PRODUCTION AND UTILIZATION ........................................................................... 796

Topics: Forage planning and management ................................................................................................ 796

Nutritional Characteristics of Different Grass and Legume Mixtures Estimated in In Sacco and In Vitro Gas Production Yvette Giramahoro, Callixte Karege1, Horacio Gonda and Mupenzi Mutimura .................................................................................................................. 797


Maintain forage yields in long- and short-term grasslands in Norway Sturite, I; Maeland, T, Høglind, M. .................................................................................................................................................. 807

Regeneration of old ungrazed old man saltbush (Atriplex nummularia) stands in south-west Australia Bennett, S.J., Low, SG., Collins, D. and Crouch, V .................................................................................................................. 811

THEME 2: FORAGE PRODUCTION AND UTILIZATION ........................................................................... 815

Topic: Forage and Animal Nutrition ........................................................................................................ 815
Isolation and Identification of Lactic Acid Bacteria Strains and their Effects on the Fermentation Quality of Elephant Grass (Cenchrus purpureus) Silage Azizza Mala, Babo Fadlalla, Zhihao Dong, Junfeng Li and Tao Shao...................................................................................................................816

Effectiveness of solarization pre-treatment for improvement of feed value of straws by white rot fungi inoculation  J. Njolomba, M. Hanada S. Muyila, N. Fukuma, T. Neshida, T.Sato , M. Yamakawa........820

The CROPGRO Perennial Forage Model Simulates Productivity and Re-growth of Tropical Perennial Grasses Boote, K.J.; Pequeno, D.N.L., Alderman, P.D., Rymph, S.J., Lara, M.A.S. .........839

THEME 3 - LIVESTOCK PRODUCTION SYSTEMS......................................................................................................................828

Topic: Utilization of Grasslands/Rangelands  ..........................................................................................................................828


Where is the livestock future – plate- or land-based? The potential of knowledge-based, holistic grazing concepts for altering grazing livestock systems Juliane Horn, Johannes Isselstein........835

Diet selection by goats at Kalemando, North Darfur, Sudan Abdelrahim.I.H.Mansoor1, Babo Fadlalla...........................................................................................................................................839

Choosy grazers and plant communities – Interactions between cattle breeds and vegetation in semi-natural pastures Pauler C.M.; Isselstein J.; Berard J.; Braunbeck T.; Schneider M.K.....................843

THEME 4: WILDLIFE, TOURISM AND MULTI-FACETS OF RANGELAND/GRASSLAND..............................................................................................................................................................848

Topic: A Revolution in Conservation Innovation By and With Pastoralists: Examples from Kenya, Africa and the globe...........................................................................................................................848

Conservation Innovation in Pastoral Lands around the Globe: Challenges, Lessons and Opportunities Reid, R.S., Colorado State University, Fort Collins, Colorado, USA.................................849

Social-Ecological Innovations and Outcomes of Community-Based Conservation in Africa: Implications for the Future Galvin, K.A..................................................................................................................854

Wildlife Conservation Innovations in a Rangeland under Rapid Change in Maasailand of Kenya Parmisa, N. and Reid, R.S..................................................................................................................857

When good conservation becomes good economics – choice of policy scenarios Said, M.Y.1, Damania, R., Desbureaux, S., Scandizzo, P. L., Mikou, M., and Gohil, D...........862

THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES .................................................................................................................................867

Topic: Gender and indigenous perspectives for sustainable rangelands: gendering and decolonizing pastoralist studies and rangeland conservation .................................................................................................................................867

Knowledge about and knowledge with: contributions from feminist research to knowledge co-production for pastoral systems Ravera F., Fernández-Giménez M., Oteros-Rozas E............868

Sustainable development and the transformation of female rural labor: The case of woman cattle ranchers in Uruguay Cordin, V..................................................................................................................874

Revitalizing Pastoral Calendars: Snowcover, Seasonal Migration, and Pastoral Decisions from Alai Valley of Kyrgyzstan Kazeiv, Daler. .................................................................879

Socially differentiation in (agro)pastoral climate change adaptation: Intersectional perspectives on socio-technical change in Kenya and Burkina Faso Todd Crane, Lisa Nebié and Teresiah Ng’ang’a ..................................................................................................................883

Women’s empowerment for demographic issues and conflicts in African pastoralist societies Cevallos, M.R. and Manzano, P..................................................................................................................889
THEME 7. CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS

Topic: Re-envisioning Rangelands in the 21st Century: Overcoming the Marginalization Narrative

Creating win-win policies for sustainable pastoralism Huber-Sannwald, E.1, Martínez-Tagüeña, N2, Espejel, , Reyes Gómez, V. M., Lucatello, S., Lauterio Martínez, C. L., Arredondo T.......................895

Mongolian herders’ evaluation of rangeland ecosystems services, values, and changes over the past decade Ulambayar, T, Yunden, B, Davaasuren, N, Balt, S, Davaajav, D, Zambuu, B.................899

Conceptualizing Pastoral Development Based on Carbon Sequestration: The Case of Yabelo District in the Southern Ethiopian Rangelands Coppock, D. L.................................................................904

Re-envisioning Global Rangeland Stewardship: An Ecosystem Services Assessment Framework Briske, David D...............................909

CLOSING REMARKS .........................................................913

CLOSING REMARKS BY DR. ELIUD KIREGER, DIRECTOR GENERAL (DG), KENYA AGRICULTURAL RESEARCH ORGANIZATION (KALRO), NAIROBI, KENYA.........................913

CLOSING REMARKS BY MR. HARY KIMTAI, PRINCIPAL SECRETARY (PS), STATE DEPARTMENT OF LIVESTOCK (SDL), MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVES (MALFC), NAIROBI, KENYA..................................................915

RAY SMITH, CHAIR OF CONTINUING COMMITTEE OF THE INTERNATIONAL GRASSLAND CONGRESS—CLOSING CEREMONY SPEECH—JOINT IGC/IRC CONGRESS KENYA 2021.....919
CONCURRENT SESSION 1

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Remote Sensing, Risk Analysis and Land Management
Rangelands Vegetation mapping at Species Composition level using the -SPix method: SDM based Pixel Classification and Fuzzy accuracy. A new approach of map making

Toxopeus, A.G.\textsuperscript{1}; De Bie, C.A.J.M.\textsuperscript{1}; Kloosterman, E.H.\textsuperscript{1}; MbalukaJ.K.\textsuperscript{2}; Mwangi, P.\textsuperscript{3}; Boerboom, L.G.J.\textsuperscript{1}.

\textsuperscript{1}University of Twente, The Netherlands; \textsuperscript{2}National Museum, Kenya; \textsuperscript{3}Consultant, Kenya.

Key words: [SPix; rangelands vegetation map; floristic composition; SDM; NDVI; fuzzy accuracy]

Abstract
Vegetation maps have been made since centuries. The vegetation cover was represented as homogeneous mapping units (polygons), representing different vegetation types, where each type consists a combination of different plant species (floristic composition). More recent, with the use of satellite imagery, the polygons have been replaced by pixels with similar content as the polygon maps. In both approaches, field-observations were linked to the mapping units (polygons or pixels) often resulting in a complex of different vegetation types per mapping unit. In our new approach field data (sample points) on presence and abundance of individual grass species are spatially extrapolated based on a set of environmental layers, using the species distribution modelling approach (SDM). When combined, each pixel will contain its own set of information about the vegetation structure and its floristic composition. This new methodology (SPix) results in a very accurate and detailed vegetation map at pixel level, allowing extraction of very detailed, accurate and easy to update spatial information on for example, forage production and quality (palatability) for rangelands management. As no exact boundaries exist, but only gradients, we introduced fuzzy accuracy. The resolution mainly depends on the resolution of (or one of) the environmental layers used, scale of interest and workability. The methodology is generic and applicable to any other region in the world.

Introduction
Vegetation maps, especially in rangelands, are often based on complexes of different grass species with varying abundances and cover percentages. Variations in the spatial distribution of the rangelands vegetation types and species abundances and cover are often influenced by rainfall, soil and relief (Reed et al., 2009). These maps can be used for rough estimations of grasslands quality, but for more reliable estimations mapping units with complexes of different species with different palatability are often too general and coarse for accurate estimations of species composition, and palatable biomass production. Given the importance of these variables in management of rangelands, this paper describes a generic method for the compilation of a detailed map containing at pixel level both the structural – and the floristic composition of the vegetation.

Methods and Study Site
The Maara Middle Basin is a typical example of a savannah ecosystem (Braun and Mungai 1981) in East Africa. The vegetation of the Maara plains can roughly be divided into woodland, bushland and grassland (Pratt and Gwynne 1977). Grasslands are predominant in the plains, while forest is mostly confined to hill crests and along the main rivers. *Chloris* spp. and *Sporobolus* spp. dominate the grasslands on basement rocks, *Pennisetum* spp. dominate on the volcanic soils in the South East. The south western part receives more rainfall and is dominated by *Themeda triandra*, while *Pennisetum mezianum* is common on the floodplains. Several grassland types include dwarf shrubs and perennial herbs, important browse plants for sheep and goats (Wijngaarden, W. van 1985).

First a preliminary stratification of the Maara Middle Basin was produced, by applying the hyper-temporal NDVI classification method (de Bie et al., 2012; Westinga et al., 2020), using 16-day composite of MODIS-Terra NDVI images (vegetation greenness index rescaled from 0 to 255 DN-Values) from January 2000 to December 2013. The classification result formed the basis for a stratified random field-sampling scheme, with emphasis on the grasslands. Fieldwork was done in October 2014 (65 samples), May 2015
(62 samples) and October 2016 (171 samples), covering both the wet and dry season. Validation of the final vegetation map was done in February 2019 (58 samples). In each sample site data on land cover, vegetation structure, grass species composition and abundance were collected. The field data were grouped into floristic vegetation types according to the Braun-Blanquet method (Braun-Blanquet 1932) and the classification result was summarized in a synoptic table (see Table 1).

To be able to produce a very detailed and accurate vegetation map at pixel level, the species distribution modelling (SDM) approach was applied (Elith and Leathwick 2009). It is pivotal to select those environmental parameters bearing significance for the environmental requirements of each grass species. The following parameters were selected: Altitude (m) and Relative Altitude (m), Slope (%), Rainfall (mm/year), NDVI-71 classes, NDVI-median, NDVI-SD and NDVI-trend. Both altitude and relative altitude were used. Relative altitude is crucial to be able to discriminate small hill-tops from depressions, as this can make a big difference in grass species presence and abundance due to difference in texture and or soil moisture. Discriminating NDVI data of MODIS-Terra satellite imagery (NASA, 2014, Lu et al., 2015) are: NDVI-71 classes is the classified hyper-temporal image, NDVI-median the long-term Median of all NDVI measurements by pixel, indicating the spatial differences in overall greenness of the vegetation, NDVI-SD which is the long-term Standard Deviation of all NDVI measurements by pixel, indicating the difference in greenness of the vegetation during seasons and years and NDVI-trend which is the long-term Trend of sequential NDVI measurements by pixel, indicating the gradual (16-daily) overall change in greenness of the vegetation during the 14 years studied.

The pixel size was set to 23 m². The MODIS products have a rectangular pixel size of 230 meters, so the pixel was divided by 10 reducing the error of the value at the outer edges. All other variables were rescaled to the same pixel size. The field sample locations were used for the grass species occurrence points. Each of the 19 most common grass species had a separate sample set and a “probability of occurrence” map was created using Maxent (Phillips et al., 2006) together with inexpensive and powerful computers, has fueled a rapid increase in predictive modeling of species environmental requirements and geographic distributions. For some species, detailed presence/absence occurrence data are available, allowing the use of a variety of standard statistical techniques. However, absence data are not available for most species. In this paper, we introduce the use of the maximum entropy method (Maxent, with a probability ranging from 0 to 100. These probabilities were rescaled from 0 to the maximum cover (%) measured during field sampling, resulting in 19 maps with a predicted grass cover of 0% up to their maximum cover % (Figure 1).

When combining these 19 predicted grass cover maps, the summed cover percentage at any sample location should correspond with the total grass cover percentage as estimated in the field. The summed “probability” map contains at any location (pixel) a combination of grass species, with a certain cover per species, which should also correspond with the sampled combination of grass species collected in the field. Finally, when clustering the many combinations resulting from the 19 combined probability maps in ERDAS (Nelson and Khorram, 2018), the number of vegetation classes in the final clustering is corresponding with the result of the floristic composition, based on the field data (Table 1).

Validation is done by taking the average AUC of each AUC belonging to each grass species probability within a grasslands class (type) weighted to the % of occurrence of that species in that grassland type (Mas et al., 2013). When summing the average AUC of the 10 grassland types the overall accuracy of the whole vegetation map has been calculated.

![Figure 1](image-url): The predicted grass cover maps with their cover range and accuracy of the prediction (average AUC of the total nr runs/species). Green dots represent the grass species samples, sized to relative cover percentage.
In nature crisp boundaries are rare, as presence and abundance of species change gradually, sometimes more sometimes less. Hence, the accuracy can never be exact, as it is a resultant of a gradient, a value range of densities of a mix of classes. Furthermore, in one (wetter) year the densities can be different from another (drier) year or season. Therefore, when checking the accuracy of the vegetation map with field observations, the results will be a proxy to reality and therefore “fuzzy accuracy” has been used as a measure of accuracy. The term fuzzy classification was used before (Reed et al., 2009), describing the accuracy of the vegetation structure classification. Here we are validating the floristic composition of the vegetation types (Table 1). The central pixel of the 58 validation field-samples, taken in February 2019, was compared with the same classified pixel in the vegetation map. Furthermore, the 9 surrounding pixels of the validation sample are also checked and averaged as was done with the surrounding 25 pixels. For each field sample the % match/mismatch with the dominant grass species in that vegetation type in the map has been estimated. When the dominant grass species are the same, a 100% match is assumed. When more dominant grass species are present, but not belonging to that vegetation type, or a dominant grass species is missing, it will reduce the 100% match according to the total number of dominant grass species.

Results
The final result was a digital high-resolution rangelands vegetation map, with emphasis on the grasses (Figure 2 and http://mara.rangelands.itc.utwente.nl/. The map is scale independent with a resolution of 23 meters square. Each pixel is representing a vegetation type (e.g., G1, G2, etc) according to Table 1, representing a certain floristic composition and abundance (cover %) of the present grass species in the selected vegetation type. Tracks and drainage have been added to the map. The floristic groups with the average of the observed cover % per grass species together with the vegetation structure are shown in Table 1.

Table 1: Structural cover and floristic groups (vegetation types) with average of the observed cover percentage per characteristic grass species, where solid-black is the dominant species, solid grey is co-dominant (cover >20%) and always present, broken solid grey co-dominant (cover <20%) but not always present, grey dots represents high cover (>20%), but sometimes present. Solid line has low cover (<20%), but always present, broken line low cover and not always present and dotted line low cover (<5%) and sometimes present.

The average AUC of the probability maps of the 19 combined grass species was 0.87 (+/- 0.03 %) at 95% confidence level, ranging from 0.77 to 0.99 (Figure 1). So based on these results the input maps can be considered as highly reliable. The fuzzy accuracy of the map, when checking with the validation field samples was 80% (+/- 7.2% at 95% confidence level), when analysed on pixel to pixel. Taken surrounding pixels in consideration, the 3x3 and 5x5 matrix had a fuzzy accuracy of respectively 78% (+/- 7.6%) and 76% (+/- 7.6%), also both at 95% confidence level, meaning the floristic composition in the produced vegetation map is at pixel level most accurate.

Figure 2: The final grasslands vegetation map at pixel level (a). Each pixel represents a vegetation class according to Table 1. The cut-outs (b and c) show a detailed part of the map where pixels can be distinguished separately (when not clustered).
Discussion
When applying the SPix approach, using SDM, it is possible to create a vegetation map with a very high resolution without any complex of different vegetation types, meaning each pixel has its own structural cover and floristic composition classification. No satellite data is needed as direct input for the classification, only needed as parameter input for the probability modelling. As no exact boundaries exist, but only gradients, we introduced fuzzy accuracy. Based on the results of the fuzzy accuracy tests the results can be considered very reliable, noting that the classification of the floristic composition is even included. The SPix method is an unique approach and gives a result at pixel level, so spatially very accurate, which can be easily updated using recent NDVI data, makes it also possible to estimate e.g., forage productivity for rangelands management including the palatability of the forage or the condition of the rangelands. The resolution is in principle unlimited and depending mainly on the resolution of (one of) the environmental parameters used, scale of interest and workability. The SPix method is facilitating management and conservation already in the Maara Middle Basis (https://www.youtube.com/watch?v=iGc22qVMrGg). The SPix method is generic and applicable for any other region in the world.

Acknowledgements

This research was done in the context of the Mau Mara Serengeti Sustainable Water Initiative (MaMaSe) programme, financed by the Dutch Government, The Haque, The Netherlands.

References


Lu, L., Kuenzer, C., Wang, C., Guo, H., Li, Q. 2015: Evaluation of three MODIS-derived Vegetation Index


Development of models for simulation of available forage Biomass in the native vegetation of the Brazilian semi-arid through remote sensing

Candido, M.J.D; Morais, L.F; Cavalcante, A.C; Costa, F.O

1Federal University Of Ceará; 2Brazilian Agricultural Research Corporation

Key words: NDVI; rangelands; surface reflectance.

Abstract
This study was carried out to verify the performance of the Normalized Difference Vegetation Index (NDVI) based on empirical models on estimating forage biomass available for animal feeding in the Caatinga biome. For two years (2018/2019), during the rainy and dry seasons, biomass harvests were performed in two permanent transects established in Caatinga vegetation composed of herbaceous, trees and shrubs and located in areas with different woody densities in Tauá, Brazil. To estimate total biomass in the field, a 0.25-m² frame was thrown 8 times in the transect for the harvest of the herbaceous layer and a 20-m² (2x10 m) frame in each quadrant of the transect for the harvest of the shrub-tree stratum biomass by the referential unit method. Sentinel 2-A (MSI) satellite images were obtained, which went through atmospheric correction by the DOS 1 (Dark Object Subtraction) method, by the Semi-Automatic Classification Plugin (SCP) routine (QGis 2.18). The normalized difference vegetation index was applied using the following formula: NDVI = (pb4-pb8)/(pb4+pb8), where pb4 and pb8 are the surface reflectances of red and infrared. For the development of the models, the LAB Fit Curve Fitting Software was used. For both D144 and D280 the exponential model presented the best fit (Ŷ =744 e ^1.3^ NDVI) and (Ŷ =2.61 e ^-0.63/NDVI^ /NDVI), respectively). An average correspondence between simulated and measured biomass was verified by analysis of the linear regression coefficient, with 69% and 62% of the variability in real biomass, explained by the simulation model results for the D144 and D280, respectively. The NDVI obtained by remote sensing associated with biomass data is a useful tool in the construction of biomass simulation models available in Caatinga rangelands.

Introduction
The Brazilian semi-arid region is mostly located in a depression, subjected to the predominance of stable air masses, presenting a unique environment where precipitation is variable and erratic. Therefore, in this Brazilian region, the predominant vegetation is the Caatinga, which presents a great floristic diversity, the result of some management of vegetation; as a result, the vegetation is composed of plants adapted to the dry climate.

The Caatinga has been used mainly for rangelands purposes, and the efficiency of the use of vegetation depends a lot on the condition of forage supply for the animals. It is known that monitoring the dynamics of rangelands is indicative of the management strategies and plans to obtain rational management and sustainability. So, remote sensing tools have significant potential to monitor vegetation dynamics, and this allows you to verify events such as the beginning or peak of vegetation growth. In addition, one of the benefits of remote sensing is the possibility of evaluating large areas with good spatial resolution and low cost.

Remote sensing is a way to capture the characteristics of large areas of the Earth’s surface. The use of this tool has helped researchers study large areas, with the possibility of acquiring images with moderately large temporal and spatial resolution relatively low cost. According to Angerer (2008), the most used models for simulating rangelands production are simple regressions, biophysical models, remote sensing techniques, or combine these methods. Remote sensing is a model category that stands out for obtaining biophysical information on vegetation indirectly and generating empirical models.

In developing empirical models, the first step consists of generating the model, which refers to obtaining mathematical equations that quantify the cause-effect relationships between
measurable variables. This study aimed to verify the performance of empirical models to predict total forage biomass through the field and remote sensing data in the Caatinga biome.

Methods and Study Site
The data collected in the field were obtained from two ecological sites, both located in the municipality of Tauá, state of Ceará, and monitored during 2018 and 2019. The two ecological sites are located on the farm “Cachoeirinha do Pai Senhor” (Latitude -5.62° S and Longitude -40.12° W), at the Barra Nova district, in Tauá. The ecological sites consisted of permanent cross-shaped transects, 25 meters long on each side from the centre, with a width of 2 m at the edge. Locations with different densities of woody plants were chosen. It was determined that the area with a density of 144 plants/ha was called Caatinga D144, and the area with a density of 280 plants/ha of Caatinga D280.

For this study, images were obtained from the Sentinel-2A satellite next to the Earth Explorer. In addition, the images were obtained from the USGS (United States Geological Survey) on the Earth Explorer platform. Images were obtained on the following dates: 04/19/2018, 05/14/2018, 06/23/2018, 07/18/2018, 10/04/2018 and 10/03/2019, which were the dates closest to the on-site collections of samples. After obtaining the data, they underwent atmospheric correction processing using the Semi-Automatic Classification Plugin (SCP) routine present as a complement for classifying satellite images of the Qgis software (2.18). The method used for correction was DOS1 (Dark Object Subtraction 1), which estimates atmospheric interference from the digital numbers (ND) of the satellite image, disregarding atmospheric absorption. After atmospheric correction was performed, the surface reflectance values were used to obtain the vegetation indexes using the raster calculator tool of the Free Software QGIS (version 2.18). The Normalized Difference Vegetation Index (NDVI) was obtained according to equation 1:

\[ \text{NDVI} = \frac{(p8-p4)}{(p8+p4)} \]

Models of vegetation with different densities of woody plants (Caatinga D144 and D280) were developed to verify the effect of density on the development of the models. Models were also tested considering the database of the two areas of Caatinga, which was called Caatinga, Tauá. The normality analysis of the data was carried out, and assuming that the data did not present a normal distribution, the Spearman correlation analysis was chosen to measure the relationship between total forage biomass and vegetation indexes. The LAB Fit Curve Fitting Software was used (SILVA et al., 2004).

For the verification and validation of the models, the comparison of the biomass values simulated by the model with the real values collected in the field through statistical tests was performed. The BIAS estimate, which reflects the normalized difference between the values simulated by the model and the real values (equation 2). The square root of the RMSE (root-mean-square error), which verifies the magnitude of the difference between the simulated biomass and the observed biomass (equation 3).

\[ \text{BIAS} = \frac{Si-Oi}{N} \]

Equation 2

\[ \text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (Oi-Si)^2} \]

Equation 3

Linear regression analysis was performed to verify the correspondence between the simulated biomass and the biomass observed through the values obtained in the determination coefficient ($R^2$). Finally, the paired t-test was applied to analyse whether the set of data obtained through simulation has a statistical difference from the real values obtained in the field. The higher the p-value, the more similar simulated and real data are. Statistical tests to evaluate the model’s performance were performed with the aid of the Statistica software.

Results
Table 1 shows the Spearman correlation values between the vegetation indexes obtained from the surface reflectance data of Sentinel-2A images and the forage biomass. In Caatinga D144, NDVI presented the average ratio (r 0,68), with forage biomass, and Caatinga D280 also showed average correlation (r 0,63).

Table 1: Spearman’s correlation between total forage biomass harvested in Caatinga D144 and D280

<table>
<thead>
<tr>
<th>Vegetation Index</th>
<th>Caatinga D144</th>
<th>Caatinga D280</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>r</td>
<td>p valor</td>
</tr>
<tr>
<td></td>
<td>0,68</td>
<td>&lt;0,05</td>
</tr>
</tbody>
</table>

The verification of the Caatinga D144 models showed a Bias error of 2,83, RMSE of 304 kg/ha and $R^2$ of 0.69, and the D280 vegetation model a
R² 0.66 and a bias error of -1.08, RMSE of 296 kg/ha and R² of 0.62. Error values positive bias show a tendency of the model to overestimate the real biomass values, while negative values a tendency to underestimate the real biomass values obtained from Sentinel 2A images and data on forage biomass harvested in Caatinga vegetation.

Table 2: Models for NDVI-based forage biomass

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Model</th>
<th>Model verification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²  RMSE  BIAS</td>
<td></td>
</tr>
<tr>
<td>Caatinga D144</td>
<td>Ŷ =744<em>exp(1.3</em>NDVI)</td>
<td>0.69  304  2.83</td>
</tr>
<tr>
<td>Caatinga D280</td>
<td>Ŷ =2615*exp(-0.63/NDVI)/NDVI</td>
<td>0.62  296 -1.08</td>
</tr>
</tbody>
</table>

Discussion
In vegetation, the reflectance in the red band tends to decrease as green biomass increases. At the same time, the structural properties of a canopy become denser, there is an increase in the near-infrared reflectance (BECK et al., 2006). So, it is the contrasts in the response of vegetation at different wavelengths that makes vegetation stand out in relation to other targets, facilitating its identification and monitoring. According to Hatfield et al. (2008), understanding leaf reflectance is important when the proposal is to monitor the vegetation by remote sensing methods. From this understanding, it became possible to create several indexes to estimate biophysical parameters of the vegetation.

There is a vast literature that links spectral indexes of vegetation with biophysical parameters of vegetation, and according to Gu et al., (2007). NDVI has been one of the most useful as it measures changes in chlorophyll content, through the absorption of red radiation, and changes in the spongy mesophyll, through the reflection of infrared radiation within the canopy of vegetation. The models developed from remote sensing data can be useful in generating maps with information on biomass production, and in preventing possible disasters caused by droughts. However, one of the limitations of empirical models is that there is a lack of confidence when it is necessary to predict biomass outside the places where they were developed, and it is necessary that it undergoes an evaluation process again when it is tested elsewhere.

Acknowledgements
The Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for financial support of the research.

References


Lowveld savanna bush cutting alters tree-grass interactions

Wedel, ER1; Nippert JB1; Swemmer AM2.

1 Division of Biology, Kansas State University; 2 South African Environmental Observation Network

Key words: [Colophospermum mopane; bush clearing; tree-grass interactions]

Abstract
Savannas are characterized by the coexistence of trees and grasses, and their interactions are modified by water availability and herbivore activity. Many savannas are experiencing bush encroachment, resulting in reduced herbaceous productivity and shifts in savanna structure. This study aims to understand the effects of tree density and tree cutting on herbaceous productivity, water use, and herbivore abundance in a mopane-dominated lowveld savanna. We present data from a 4-year mopane-cutting experiment in the Mthimkhulu Game Reserve bordering Kruger National Park (South Africa). We established three 60 x 60 m plots for experimental manipulation where mopane stems and re-sprouting shoots were cut 2-3 times per year (2015-2019). We established transects within the plots to measure grass productivity and herbivore activity (counts of tracks and dung). Additionally, we measured root non-structural carbohydrates within cut and uncut mopane to assess the impact of cutting on energy storage. We used stable isotopes of xylem and soil water at multiple depths to infer changes in functional water use of coexisting mopane and grass species. Cutting had limited effects on mopane survival during this 5-year period, but re-sprouting stems had reduced height and starch concentrations than uncut trees. Cutting mopane resulted in shallower-soil water use in 2017 and tended to increase variability in root water uptake across multiple soil depths. The cut treatment tended to have higher grass cover and productivity than the control treatment by the 3rd growing season. Visitation of grazers increased in the cut plots relative to uncut plots by 2017, suggesting increased grass cover promotes grazer visitation. These results emphasize the importance of top-down drivers on savanna tree cover and the impacts of bush encroachment on grass biomass and herbivore presence. We suggest repeated cutting or browsing pressure is needed to suppress woody cover and increase grass production in lowveld savannas.

Introduction
Savannas are characterized by the coexistence of trees and grasses. The distribution and abundance of these functional types are determined by the interactions of top-down and bottom-up drivers. These drivers include water and nutrient limitation (bottom-up) and disturbances such as fire and herbivory (top-down). The interaction and alteration of these drivers determine tree: grass ratios through the competitive and demographic limitations of tree establishment amongst a dense and highly competitive grass layer. For example, at high densities, grazers decrease grass cover and reduce subsequent fire intensity, resulting in increased tree establishment, growth, and survival (Holdo et al., 2009). In contrast, a high abundance of browsers decreases woody cover and opens the canopy for grass growth (Sankaran et al., 2013; Daskin et al., 2016). These top-down drivers determine the presence of tree demographic bottlenecks and are often associated with wetter systems. In drier systems, tree cover is also limited by water availability. Once established, woody plants are hypothesized to avoid water competition with grasses through hydrological niche separation, where trees use deeper water sources than grasses when shallow soil water availability is low. Changes in climate and land use at the global, regional, and local level have altered these top-down and bottom-up drivers that limit tree cover and have led to the increased cover of woody plants in savannas, a process referred to as bush encroachment.

Historically, woody plants in savannas have had important roles for human and ecosystem well-being including provisioning firewood and timber and an important food source for herbivores. However, an increased abundance of woody plants has led to negative economic and ecological shifts. For example, increased
woody plant density can decrease grass biomass used for domestic livestock production (Archer and Predick 2014) and may also deplete soil moisture by rainfall interception and increased transpiration (Honda and Durigan 2016). Additionally, in areas promoting ecotourism, dense tree cover can make it difficult to see large, charismatic animals that attract tourists, resulting in lost tourism revenue for local communities. Bush cutting has been used as a way to mitigate the negative effects of woody encroachment; however, manual clearing is a labour intensive and expensive management technique. Research efforts are needed to understand the effects of bush cutting on encroaching woody species and create effective management practices to increase herbaceous cover. In addition, many encroaching woody species resprout after disturbance and there is no clear understanding on the amount of repeated cutting needed for long-term reduction in tree cover.

In this study, we assessed the consequences of repeated bush cutting in a *Colophospermum mopane* (hereafter referred to as mopane) dominated semi-arid savanna at Mthimkhulu Game Reserve in South Africa. Mopane trees were cut once to twice per year from 2015-2019. We assessed the effects of bush cutting on the sources of water used by active roots and root carbon storage of mopane trees. We also examined the effects of mopane cutting on grass productivity and monitored herbivore presence via track and dung counts. We predicted repeated cutting would (1) shift mopane root water uptake to deeper soils to avoid competition with grasses, (2) deplete nonstructural carbohydrate (NSC) storage belowground, reducing energy available for resprouting after disturbance and (3) increase grass productivity and subsequently grazer presence.

Materials and Methods

**Study Site**

Mthimkhulu Game Reserve (MGR) is a 7500-hectare community-owned reserve that shares open borders with the northern portion of Kruger National Park in South Africa. The site is dominated by the C₄ grass *Urochloa mosambicensis* and has undergone encroachment by mopane, a dominant tree in the northern half of Kruger National Park. Mopane can form dense, monodominant stands that shade out herbaceous species living in the understory. In 2015, we established three 60 x 60 m plots and randomly assigned half of each plot to a repeated cutting treatment. Within the cut treatment, mopane trees standing < 4 m tall were cut at the base 1-2 times per year and measurements began in 2016. Within each plot, we established two 2 m wide x 50 m long transects. Animal tracks and scat along these transects were identified to species. Grass biomass (g m⁻²) was clipped in four 0.5 x 0.5 m quadrats in each plot. Samples were dried at 80°C for two days and weighed.

To assess if bush clearing causes plants to shift their root water uptake, we matched the stable isotopic signature of xylem water of mopane trees and grasses to that of the soil water at various depths in the soil profile (protocol outlined in Nippert and Knapp 2007). To assess differences in water use, we analysed each year (2016-2018) separately. Since δD and δ¹⁸O were collinear and varied similarly with soil depth, we collapsed δD and δ¹⁸O into a single axis using PCA to analyse both water isotopes in a single analysis (see Holdo et al., 2018 and Case et al., 2020). The PCA approach is a useful alternative to isotope mixing models when plant isotopic signatures fall outside of the range of sampled soil isotopic signatures, indicating plants are using water from deeper sources than the soil sampled. To assess root NSC, mopane root samples were collected 20-30 cm below the soil surface at the same time as samples for isotopic analysis. NSC extraction followed the procedure outlined in O’Connor et al., 2020. We used R program to analyse differences between cut and uncut treatments using mixed effects ANOVAs with plot as a random effect to account for inherent variation between plots.

**Results**

Soil water isotopic composition tended to become depleted with depth, whereas shallow soil layers had isotopically enriched signatures. PC1 declined significantly as log-transformed depth increased in 2017 and 2018 (P < 0.05) and moderately in 2016 (P = 0.068). Mopane trees used deeper soil water than grasses (P < 0.05; Figure 1). In 2017, mopane trees used shallower soil water than uncut trees (P < 0.05; Figure 1) but there were no significant differences in source water use in 2016 and 2018. Variability in mopane source water use was high in all treatments but cutting tended to increase this variation. On average, the coefficient of variation of cut trees were 1.4, 2.7, and 1.2 times greater than uncut plots in 2016 - 2018, respectively.
NSC starch concentrations were significantly lower in cut than uncut mopane trees in 2016-2018 ($P < 0.05$). Differences in starch concentrations between cut and uncut mopane trees increased with repeated cutting, where average starch concentrations were 1.8, 2.6, and 7.8 times greater in the uncut than cut trees in 2016-2018, respectively.

In 2017 and 2018, grass biomass (g m$^{-2}$) tended to be higher in cut than uncut plots, but one plot in the uncut treatment diminished these differences in 2019 and differences were not significant. By 2017, track and dung counts tended to be higher in the cut than uncut plots indicating higher animal presence. Grazer track and dung counts were significantly higher in cut than uncut plots in 2018 and 2019 ($P < 0.05$) for herbivores including buffalo, hippo, impala, warthog, waterbuck, wildebeest, and zebra (Figure 2).

**Discussion [Conclusions/Implications]**

The increased cover of woody species has caused numerous economic and ecological consequences in lowveld savannas. In areas where the drivers limiting woody cover have been altered, bush cutting may be a necessary management technique to increase grass cover and reverse the negative consequences of bush encroachment. Active and frequent management practices are likely to become increasingly necessary in a changing climate and fragmented landscapes where the return of disturbance to the system is insufficient to limit bush encroachment (Case et al., 2017; Collins et al., 2021). In this study, we found repeated cutting reduced mopane starch reserves and opened the canopy, promoting increased grass productivity and herbivore presence. Although we did not find consistent significant shifts in root water uptake by mopane in response to cutting, our results support hydrological niche separation between trees and grasses (Holdo et al., 2015; Case et al., 2020). Mopane roots have been shown to be shallow with the majority of fine roots in the top 40 cm of soil and coarse roots between 40-60 cm of soil (Smit and Rethman 1998). This shallow and sprawling root system suggests shallow roots play an important functional role for the species and differences in niche partitioning between trees and grasses may occur over small spatial scales (Kulmatiski and Beard 2020). Slight increases in variation in cut mopane water use may be associated with increased plasticity. Repeated cutting may reduce belowground carbon investment and increase reliance on fine roots in the surface soils, as seen in 2017.
Five years of repeated cutting resulted in low tree mortality, but significantly decreased root starch concentrations. Woody plants in disturbance-prone areas tend to have high NSC storage belowground used to resprout after disturbance (Wigley et al., 2019). Repeated cutting depleted NSC reserves and starch concentrations became lower in the cut trees over time. This suggests that mopane trees are not able to restore belowground carbon stores when faced with frequent and repeated disturbance. Interactions among multiple disturbances (e.g., cutting and fire) have the potential to result in even greater reductions in NSC concentrations, with resulting increased tree mortality (O’Connor et al., 2020). Imposing multiple disturbances likely holds the most promise to drive the long-term reduction of woody cover in mopane savanna. Perhaps most importantly, in locations with cut mopane, we found increased grass biomass and signs of herbivores within only a few years. Increased grazer presence may have both ecological and applied benefits for the landscape. In summary, this study shows bush cutting requires repeated and active management but can be an effective management tool for decreasing woody cover and promoting herbaceous biomass and herbivore presence within sites.

Acknowledgements

We thank the Mthimkhulu Game Reserve for access to the site and the many individuals in the Working for Water programme in South Africa who maintained the bush clearing treatments. In particular, we thank Peace Nkuna for logistical support, project maintenance, and ecological insight. We also thank the South African Environmental Observation Network, the National Science Foundation (Award # 1928875), and the Division of Biology at Kansas State University for financial support.

References


Multifunctionality of sown grassland is enhanced by combining four complementary species

Suter, M.1; Huguenin-Elie, O.2; Lüscher, A.2

1Agroscope, Forage Production and Grassland Systems, Reckenholzstrasse 191, 8046 Zürich, Switzerland; 2Agroscope, Forage Production and Grassland Systems, Reckenholzstrasse 191, 8046 Zürich, Switzerland

Key words: Diversity experiment; forage production, grass-legume mixtures, log response ratio, sustainable agriculture

Abstract
We investigated species diversity effects and multifunctionality in an intensively managed grassland. A diversity experiment was set up with monocultures and mixtures comprising Lolium perenne, Dactylis glomerata, Trifolium pratense, and Trifolium repens, and was maintained for three years at 150 kg·N·ha⁻¹·year⁻¹. Ten functions were measured that represented i) forage production (aboveground biomass yield (µ), standard deviation of yield (σ), temporal stability (µ/σ), weed biomass), ii) N cycling (symbiotic-N₂-fixation, N efficiency, NO₃ in soil solution), and forage quality (crude protein content (CP), organic matter digestibility (OMD), metabolizable energy (ME)). We applied multivariate linear mixed-effects regression to estimate simultaneously species identity and diversity effects on the ten functions, and used the mean log response ratio (MLRR) across all functions to evaluate the diversity-multifunctionality relationship.

Across the three years, all functions regarding production and N cycling revealed significant beneficial effects in the four-species equi-proportional mixture (used as a reference) compared to averaged monocultures. The reference mixture had 61% more biomass yield, 8% less variation, 68% higher stability, 81% less weed biomass, 96% and 46% higher symbiotic-N₂-fixation and N-efficiency, respectively, and 87% less NO₃ (each P ≤ 0.05, except variation). The reference mixture and averaged monocultures did not significantly differ in CP, OMD (g·kg⁻¹·yield), and ME (MJ·kg⁻¹·yield). This, however, resulted in significant beneficial effects between 52% and 72% in all three forage quality functions on a hectare basis (kg or MJ·ha⁻¹·year⁻¹). On average across functions, the four-species reference mixture had 1.8 times the performance of averaged monocultures, indicating enhanced multifunctionality in mixtures.

The multivariate framework in combination with the MLRR as a measure of overall multifunctionality proved to be an effective tool for the evaluation of the diversity-multifunctionality relationship. We conclude that sown grass-legume mixtures at moderate N fertilization promote high multifunctionality and are a ‘ready-to-use’ option for sustainable intensification of agriculture.

Introduction
There is evidence that higher plant species diversity promotes many relevant key ecosystem functions in agroecosystems, such as nutrient provision and biomass production (Allan et al., 2013). Due to the many functions benefiting from an increase in the number of plant species, higher species diversity is also thought to enhance overall multifunctionality (Lefcheck et al., 2015). This positive effect of species diversity arises because different species can be relevant to maintain different functions, or functions under different conditions.

Intensively managed grasslands have high economic and agronomic importance (O’Mara 2012). Such grasslands naturally contain fewer plant species than nutrient poor, extensively managed grasslands because only few species can cope with the short defoliation intervals in intensively managed systems. Given these conditions, it remains open whether only small increases in species richness positively affect multifunctionality. Despite the importance of productive grasslands, their diversity-multifunctionality relationship has never been evaluated.
Here, we investigate effects of species diversity on multifunctionality in an intensively managed grassland. A multivariate modelling framework was applied to simultaneously test for species interactive effects on multiple functions and their relative importance on overall multifunctionality (Dooley et al., 2015). Moreover, we developed a novel approach to measure multifunctionality using a mean log response ratio (of higher diversity mixtures against monocultures), which overcomes the generally acknowledged limitations of current methods (Gamfeldt and Roger 2017). We primarily tested whether increasing species diversity from monocultures to mixtures with only four species enhances overall multifunctionality. To this aim, we also investigated whether species complementarity effects on individual functions resulted in beneficial mixture effects driving the overall diversity-multifunctionality relationship.

Methods and Study Site
We used a dataset from a grassland diversity experiment at Zürich-Reckenholz, Switzerland, in the Atlantic central climatic zone of Europe. Four key forage species for ruminant production were selected based on the factorial combination of their functional traits related to temporal establishment and N acquisition (non-fixing for grasses, N-fixing for legumes). The species were *Lolium perenne* L. (fast-establishing grass), *Dactylis glomerata* L. (temporally persistent grass), *Trifolium pratense* L. (fast-establishing legume), and *Trifolium repens* L. (temporally persistent legume). Species were sown as monocultures and mixtures at a wide range of species relative abundances, and stands were maintained for three years following establishment. All plots received phosphorus and potassium in non-limiting amounts, and nitrogen (N) fertilization was 150 kg N ha\(^{-1}\) year\(^{-1}\). In total, 42 plots (3 m × 6 m) were established and arranged in a fully randomised design. Consult Nyfeler et al., (2009) for full details of the experimental design, establishment, and maintenance.

Ten functions were measured representing i) forage production: aboveground biomass yield, standard deviation of yield, temporal stability, weed biomass; ii) N cycling: symbiotic N\(_2\) fixation, N efficiency, NO\(_3\) in soil solution; and iii) forage quality: crude protein content, organic matter digestibility, metabolizable energy content (Table 1). The measurement of all functions followed standard practices and is described elsewhere (Lehman and Tilman 2000; Nyfeler 2009; Nyfeler et al., 2009; Nyfeler et al., 2011; Agroscope 2013).

We applied the multivariate modelling framework (Dooley et al., 2015) to estimate simultaneously species identity and diversity effects of the ten functions. Linear mixed-effects regression was used to estimate parameters for each of the ten functions and the four species in monocultures and mixtures. The model included parameters for interactions between the grass and legume species, interactions between the two grass species, and between the two legume species. Based on the estimated model parameters, we calculated the beneficial mixture effect (BME) for each of the ten functions with:

\[
\text{BME}_k(\%) = \frac{\bar{y}_{\text{equi}_k} - \bar{y}_{\text{avmono}_k}}{\bar{y}_{\text{avmono}_k}} \times 100
\]

with \(\bar{y}_{\text{equi}_k}\) being the predicted functional performance of function \(k\) at the four-species equi-proportional mixture (chosen as a reference) and \(\bar{y}_{\text{avmono}_k}\) the predicted performance of the average of monocultures. The diversity-multifunctionality relationship was evaluated using a new measure, the mean log response ratio (MLRR), which is the average of the log response ratios of all functions at the four-species equi-proportional mixture compared to the average of monocultures. For functions, where minimal values were regarded as positive benefit, their LRR was first multiplied by -1. As such, a significantly positive MLRR indicates a positive diversity-multifunctionality relationship. All analyses presented here refer to data averaged across the three experimental years.

Results

Beneficial species interactions in mixtures
We observed highly significant species interactions in mixtures that favoured the majority of functions. Beneficial interactions were strongest between grass and legume species (being complementary in N acquisition), and – although to a lesser extent – were also evident between the two grass species and between the two legume species (each pair being complementary in temporal establishment; no table shown).

The cumulative effect of all species interactions led to beneficial mixture effects for all forage production and N cycling functions (Table 1). For example, the four-species equi-proportional reference mixture had 61% more yield, 8% less variation (SD\(_{\text{yield}}\)), 68% higher stability, 81% less weed biomass, 96% more symbiotic N\(_2\) fixation, 46% higher N efficiency, and 87% less NO\(_3\) in the soil solution compared to averaged monocultures (each at least \(P \leq 0.05\), except SD\(_{\text{yield}}\). NO\(_3\) in the soil solution of mixtures was negligibly low (< 0.1 mg NO\(_3\)-N liter\(^{-1}\)). For the three forage
quality functions, there were next to no mixture benefits if functions were expressed as content (g kg\(^{-1}\) yield in CP and OMD, MJ kg\(^{-1}\) yield in ME, Table 1). Notably, this outcome appeared despite significantly higher yield in mixtures. As a result, CP, digestible OM, and ME per hectare (ha\(^{-1}\) year\(^{-1}\)) were much greater in mixtures than in averaged monocultures, with beneficial mixture effects being in the range of 52-72%.

**Table 1:** Percent beneficial mixture effects for ten functions representing forage production, N cycling, and forage quality, measured over three experimental years. *** \(P \leq 0.001\), ** \(P \leq 0.01\), * \(P \leq 0.05\), ns: \(P > 0.05\)

<table>
<thead>
<tr>
<th>Service</th>
<th>Function</th>
<th>Unit (Ratio)</th>
<th>Targeted direction</th>
<th>Beneficial mixture effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td>Aboveground biomass yield</td>
<td>Yield</td>
<td>Mg ha(^{-1}) year(^{-1})</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>Standard deviation of yield</td>
<td>SD(_{yield})</td>
<td>Mg ha(^{-1}) year(^{-1})</td>
<td>negative</td>
</tr>
<tr>
<td></td>
<td>Temporal stability of yield</td>
<td>Stability</td>
<td>(\text{Yield} / \text{SD}_{yield})</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>Aboveground weed biomass</td>
<td>Weed biomass</td>
<td>Mg ha(^{-1}) year(^{-1})</td>
<td>negative</td>
</tr>
<tr>
<td><strong>N cycling</strong></td>
<td>Symbiotic N(_2) fixation</td>
<td>(N_{sym})</td>
<td>kg ha(^{-1}) year(^{-1})</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>N efficiency</td>
<td>(N_{efficiency})</td>
<td>(N \text{ yield} / N \text{ applied})</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>(\text{NO}_3) in soil solution</td>
<td>(\text{NO}_3)</td>
<td>mg liter(^{-1})</td>
<td>negative</td>
</tr>
<tr>
<td><strong>Forage quality</strong></td>
<td>Crude protein content</td>
<td>CP</td>
<td>g kg(^{-1}) yield</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>Organic matter digestibility</td>
<td>OMD</td>
<td>g kg(^{-1}) yield</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>Metabolizable energy content</td>
<td>ME</td>
<td>MJ kg(^{-1}) yield</td>
<td>positive</td>
</tr>
</tbody>
</table>

**Significantly enhanced multifunctionality in mixtures**

Beneficial mixture effects were evident without trade-off between functions (Table 1). Due to this result, multifunctionality was significantly enhanced in mixtures, with the four-species equi-proportional mixture having on average 1.8 times the performance of averaged monocultures (Figure 1).

**Figure 1:** Enhanced multifunctionality in grass-legume mixtures expressed as the mean log response ratio (MLRR) (horizontal line) across ten functions (circles). The log response ratio was calculated for each function for a mixture with equal proportions of all four species compared to averaged monocultures, based on multivariate regression analysis. The inference (\(t\)- and \(P\)-value) refers to a test of the MLRR against zero. Circles are slightly scattered horizontally to improve their visibility.

**Discussion**

Our selected species were cultivars known to perform well in pure stands under intensively managed conditions. However, it was not clear how their combination in mixtures affects multifunctionality, as multifunctionality also depends on the species’ interactions within a community. It is therefore surprising and of high practical importance that multifunctionality was enhanced by a factor of almost two by using only four species. We attribute this strong diversity effect to the targeted combination of species with...
complementary functional traits (Lüscher et al., 2011; Storkey et al., 2015).

In our grass-legume system, species complementarity in N acquisition was most important to result in beneficial mixture effects for many functions. Legume species are capable of symbiotic N$_2$ fixation, which allows them to cover their own N demand, while grass species rely solely on N uptake from soil and fertilizers. Moreover, growing these species in mixtures allows for transfer of symbiotically fixed legume N to the grasses (Høgh-Jensen and Schjoerring 1997; Nyfeler et al., 2011). Previous studies have shown that these processes substantially enhance biomass and protein yield (Nyfeler et al., 2009; Nyfeler et al., 2011; Suter et al., 2015), improve stability (Haughhey et al., 2018) and enhance weed suppression (Suter et al., 2017; Connolly et al., 2018). In our experiment, positive interactions between legume and grass species also increased N efficiency and kept NO$_3$ in soil solution at low levels. Additional analyses revealed that complementarity in temporal establishment further improved yield and stability, and suppressed weeds, all of which are highly important for sustainable production.

Our new measure, the MLRR across functions, proved to be valuable in evaluating overall multifunctionality. The log response ratio is easy to apply and is widely used in ecology, probably because of its desirable statistical properties (Hedges et al., 1999). In our approach, the individual drivers of multifunctionality could still be identified through the multivariate modelling framework (Dooley et al., 2015), which is important to identify opposing behaviours between single functions and overall multifunctionality. Knowledge of both, the performance of individual functions and overall multifunctionality, is essential for appropriate decisions for management and stakeholders.

We have demonstrated that grass-legume mixtures increased yields with no decrease in forage quality, increased stability, maintained weed suppression, enhanced N efficiency but reduced N leaching to low levels, all of which increased multifunctionality. These features align well with recent demands to produce more with same resources and concomitantly preserve the environment (Godfray and Garnett 2014). The species of our experiment are used worldwide in production-oriented grasslands and their cultivation in mixtures provides a ‘ready-to-use’ approach. Given their many benefits and the lack of adverse effects on the environment, legume-based multispecies grasslands should become a key option for the sustainable intensification of agriculture.

References


Effects of herding on rangeland use efficiency in Kenya

Seidel, A.; Asch, F.; Warth, B.

1 Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute), University of Hohenheim

Key words: stocking rates; hired herders; Kenya; palatability of rangeland resources

Abstract

Within each foraging itinerary, herders can intervene in the forage selection process, encouraging herds to use highly palatable and less palatable rangeland resources. Such a herding strategy could prevent rangeland degradation and increase livestock productivity. The objectives of this study were to examine forage availability and identify factors influencing stocking rates around night resting places on a ranch in Laikipia County, Kenya.

Forage availability was measured along six regularly spaced transects around night resting places corralling one herd of camels, one mixed herd of goats and sheep, and two herds of cattle, with biomass sampling points at 50-, 150-, 250-, and 350-meter distance from the night resting places. Every four days, herbaceous biomass was collected at each sampling point and classified into monocotyledonous plants, dicotyledonous plants, and litter. Pooled samples of biomass were analyzed for their nutrient content. Activities of herders and herds were monitored. Stocking rates were calculated for the sampling points using georeferenced data of foraging itineraries recorded in 20-second intervals, area densities of herds measured by a hand-held global positioning system receiver, and live weights of all animals determined monthly.

Except for the herd of camels, the distance to the night resting places had no effect on stocking rates. Not forage nutritive value, but palatability of dominant species on sampling points mainly influenced stocking rates, and thus forage availability. All livestock species sought patches dominated by Cynodon dactylon, possibly being overgrazed. Patches dominated by either Andropogon contortus or Themeda triandra were underused, as indicated by biomass accumulation. Thus, the efforts of the hired herders in this study did not lead to the desired herding effects. Therefore, motivating herders to design foraging itineraries utilizing diverse vegetation patches intentionally is crucial to an efficient use of rangeland resources, while meeting the nutritional requirements of animals.

Introduction

Herders can control the foraging areas and diet selection of herds over daily foraging itineraries to stimulate feed uptake of both highly palatable and less palatable plants, while meeting the nutritional requirements of the animals and potentially mitigating rangeland degradation (Meuret and Provenza 2014). In line with this, herders can encourage goats to browse, and sheep to be intermediate feeders, and thus reducing the dietary overlap between different livestock species (Samuels et al., 2016).

Most prior work has analyzed the impacts of herders on daily foraging itineraries, but has not considered the availability of forage resources (e.g. Coppolillo 2000; Turner and Hiernaux 2002). Many other studies have related the distribution of livestock to the rangeland resources around livestock concentration locations at the landscape level, with little attention directed to herd movements with respect to vegetation resources in close proximity of livestock concentration locations (e.g. Turner et al., 2005; Butt 2010). The lack of intensive and continuous monitoring of interactions between hired herders, herds of different animal species, and their environment at patch level limits the understanding of resource utilization patterns and variables shaping daily foraging itineraries under restricted mobility. Examining the variability among individual vegetation patches around night resting places and their influencing factors can raise awareness of factors affecting rangeland health and livestock productivity.
In Laikipia County, Kenya, most of the land is under large-scale ownership and many landowners are engaged in livestock and crop production and in wildlife tourism and management (Bond 2014). On privately owned ranches, herders have been employed to daily tend to livestock (Yurco 2017). These herders take the animals to foraging areas and watering places, and overnight, the animals are corralled in night resting places, built from brushes of Acacia species. The presence of diverse livestock species, heterogeneous forage resources, and relatively well predictable sizes of herds and movements of herders on ranches provide an interesting study scene to describe the relationships between vegetation, livestock, and humans in semi-arid rangelands at patch level. Therefore, an in-depth case study approach was employed with the overall objective to improve the understanding of vegetation dynamics and stocking rates, and with this daily foraging itineraries designed by hired herders around night resting places in a semi-arid rangeland at patch level. The results of this study can imply strategies to improve rangeland use efficiency on ranches.

Materials and Methods

Study Site

To examine the relationships between herd movements directed by herders and forage resources at patch level, six regularly spaced transects around night resting places with biomass sampling points at 50-, 150-, 250-, and 350-meter distance from the night resting places were established between June and September 2018. The two dominant plant species recorded at each sampling point defined vegetation patches. Baseline conditions were determined at each characterized sampling point, before one herd of camels (n = 44), one mixed herd of goats and sheep (n = 93), and two herds of cattle (n = 89; n = 86) were moved to the night resting places. Thereafter, measurements at each sampling point were carried out every four days during the use of the night resting places, and thrice after the herds were moved to another night resting place. These representative quadratic sampling areas of one square meter, with at least one-meter distance among them, were randomly chosen. Samples were taken at about 1.5 cm above ground level and sorted by monocotyledonous plants, dicotyledonous plants, and litter. Dry matter, crude nutrients, fiber fractions, and organic matter digestibility were determined for the pooled samples. Forage analyses were done according to VDLUFA (2012).

Additional data was collected through participant observation, and perceptions were collected through in-depth interviews and informal conversations with herders to complement the quantitative research findings.

The length of daily foraging itineraries was determined by two global positioning system devices, each carried by a randomly selected animal of each herd and recording the position of the animal every 20 seconds. Area densities of herds were measured by a global positioning system device from the ground by walking around the herd at 20-minute intervals, and in case of the herd of camels every 40 minutes. All animals were weighed monthly. To calculate the stocking rates at each sampling point, the time herds spent on each sampling point, area densities of herds, and live weights were used. Calculations were carried out in QGIS (Version 3.0.3) and in Microsoft Excel (Version 2016).

With the help of the GLIMMIX procedure of SAS (Version 9.4), the driving forces behind the stocking rates were analyzed. The full model for each herd and night resting place consisted of the quantitative fixed effects date, the dry matter weight of the herbaceous biomass fractions (monocotyledonous plants, dicotyledonous plants, and litter), the specific nutritional quality, mean height of herbaceous biomass, cumulative amount of precipitation and maximum ambient air temperature. Furthermore, the examination of the qualitative fixed effects included transect, distance to the night resting place, identified vegetation patch, palatability, and sampling point description. In addition to the relevant effects, spatial and temporal autocorrelations were modelled by introducing additive random effects into the model. Non-significant effects (P ≥ 0.05) were dropped from the models to obtain a reduced model. The corrected Akaike information criterion was used to evaluate the developed models.

The ranch Ol Maisor, located in the Rift Valley at about 1,870 m above sea level and covering an area of approximately 11,500 ha, was selected due to its relatively good infrastructure and facilities.

Results

The dominant plant species encountered on the sampling points were Indigofera volkensii, Cynodon dactylon, Melhania ovata, Themeda triandra, Andropogon contortus, Lintonia nutans, and Solanum inerum. Vegetation dynamics around the night resting places differed between sampling points. After the abandonment of the night resting places, vegetation patches dominated by C. dactylon were possibly overgrazed, as indicated by relatively low dry matter weights (about 35 g/m²), and those dominated by either...
A. contortus or T. triandra were most likely underused (about 560 g dry matter/m²).

The herd patterns over daily foraging itineraries were principally related to the interventions and positions of herders and vegetation structure. Constant area densities of the herd with lactating cows over daily foraging itineraries between recorded positions of the herder suggest that the herder was in control of the herd patterns from every position. Over daily foraging itineraries, the herder slowed the movement speed of animals down by forming a foraging front, most likely mitigating rapid selection. The animals of the other herd of weaner cattle at the front of the usual circular herd pattern probably carried out rapid selection due to the following animals, while the animals in the middle and at the back of the herd fed on the forage resources left by the leading animals.

Herders were allowed neither to keep their own livestock nor to have any kind of share in the animals on-site. They explained that they had utilized forage resources more flexible before working on the ranch. The owners and the herders admitted that the forage and livestock management was not optimal. Herders did not fully incorporate their knowledge to improve the exploitation of different vegetation patches, because they left the herds every so often to expand contacts, buy leaves of the plant Catha edulis or any other item, or go hunting. Herders added that they spared no effort to satisfy the feeding requirements of a herd with lactating cows to increase milk yields, as they were entitled to milk for their personal use. They also felt proud of well-nourished and healthy animals, which they showed other herders, workers, and officials.

Each herd visited the sampling points around the night resting places to a variable extent. All herds showed a patchy utilization of forage resources around night resting places, frequently travelling to the same sampling points, especially in the morning and in the late afternoon. The effects of distance to the night resting place and palatability were important drivers for the stocking rates of the herd of camels, according to the selected generalized linear mixed models. The stocking rates of the mixed herd of goats and sheep around the night resting places were strongly influenced by palatability and dry matter weight of dicotyledonous plants around the night resting places. Both herds preferably utilized patches dominated by the highly palatable species I. volkensii and C. dactylon (P < 0.01). The stocking rates of the herds of cattle around the night resting places were significantly associated with the effects of transect, palatability, and dry matter weight of monocotyledonous plants. Both herds of cattle predominantly sought vegetation patches dominated by the highly palatable grass C. dactylon (P < 0.01). Across all months, organic matter digestibility of C. dactylon (ranging from 607 to 696 g/kg dry matter) was greater than the one of the other dominant plant species (averaging 503 g/kg dry matter). The transect that was established from the night resting place towards another night resting place was frequently visited by one herd of cattle (P < 0.01).

Discussion [Conclusions/Implications]

When aiming at an efficient utilization of forage resources in a semi-arid rangeland ecosystem, the foraging system has to be flexible to adapt to the highly dynamic spatial and temporal variability (Savory and Butterfield 2016). The rangeland management on the ranch under study implemented a rotational foraging system, in which the foraging area is subdivided into units that are recurrently utilized by livestock, using hired herders. It seems likely that when the quality and quantity of forage resources differed at the micro level, a rotational foraging system is suitable to respond to heterogeneity compared to continuous foraging methods. This view on rotational foraging systems is contested by Briske et al. (2008), who argue that the area has to maintain sufficient forage resources to carry animals during periods of forage scarcity, irrespectively of the management system. However, this work has not considered the knowledge of herders, who are able to improve the performance of animals by altering the movements of herds (Odadi et al., 2017). Likewise, Salomon et al. (2013) acknowledge that herders are aware of seasonally palatable vegetation patches. Since the herds around the night resting places went into distinct directions on the same day, and each herd spread out in diverse directions on different days, hired herders most likely coordinated daily foraging itineraries. Therefore, the results of this study also provide support to arguments that herd activities are significantly influenced by herders (Zengeya et al., 2015), as animals spread out in the absence of hired herdsmen. This indicates the continuous interaction between herders and herds over daily foraging itineraries (Liao et al., 2018) and their ability to intervene in the forage selection process.

Neither the vegetation dynamics nor the stocking rates around the night resting places showed either an evenly distributed foraging intensity as described by Homewood and Rodgers (1991), a decreasing one with distance in all directions or skewed toward the water source as proposed by...
Spencer (1973), or an increasing one with distance in two opposite directions as assumed by Western (1975). Although the distance to the water source most likely limited the length of the daily foraging itineraries of the mixed herd of goats and sheep, the stocking rates were not skewed toward the water sources. The distance in case of the herd of camels and the directions in case of the other herds were not gradually predictable. This study demonstrates that highly palatable sampling points around the night resting places were visited considerably more than those characterized by less palatable forage resources. This is consistent with previous work at finer scales (Provenza 1996). Hence, the relatively high stocking rates around night resting places did not change the diet selection process of animals, but rather increased the rate at which palatable species were defoliated, as also reported by Bailey and Brown (2011). This was evidenced by low plant heights and dry matter weights of the palatable forage C. dactylon that grows on abandoned night resting places. Moreover, the diversification of animal species does not relieve foraging pressure on either severely grazed or browsed plant species, but it potentially maximizes the exploitation of rangeland resources.

Previous research has found that animals forage more efficiently, when the daily distance they travel was reduced (Sevi et al., 1999). A herding system as practiced on the ranch under study has the potential to respond to naturally varying forage resources and to induce functional heterogeneity by building night resting places. To exploit the rangeland resources more efficiently, hired herders have to be motivated to intervene in the diet selection process of animals all day to avoid high stocking rates on specific vegetation patches around night resting places, while diluted impacts of stocking rates on others reduce palatability, and to encourage goats to browse. It is therefore important to ascertain the underlying reasons behind little incentives. Simple measures that could be taken to facilitate an efficient use of rangeland resources may include hiring two permanently employed herders per herd, introducing an offspring-sharing system, and negotiating agreements with neighboring landowners to increase herd mobility in case of need. The investigation of an optimal grazer-browser-intermediate feeder ratio may contribute to the increase in resource use efficiency.

Acknowledgements
This research was financially supported by the Ellrichshausen-Stiftung as part of the project “Underutilized or unprotected? New methods for analyzing diverging perspectives on the large-scale conversion of tropical grassland ecosystems”. Without its generous funding this study would have not been possible. Special thanks are given to Prof. C. Hülsebusch for organizing the research stay in Kenya, and Prof. H.-P. Piepho and Dr. J. O. Ogutu for their statistical support. Sincere gratitude goes to the participants and respondents in this research.

References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Temperate/Tropical Transition Climate Zones: Locations for Breeding Forages with Climate Resiliency
Temperate/tropical transition zones: a hotspot for breeding forages with climate resiliency

Quesenberry, K. H.; Rios, E. F.; and Kenworthy, K. E.

1Department of Agronomy, University of Florida, Gainesville, FL 32611 USA

Key words: climate change; forage breeding; pest resistance

Abstract
Species resiliency to climate change is critical for the sustainability of grassland agricultural systems. Transition zones between temperate and tropical climates (between 27 and 31° N and S latitude) with variable annual frost/freeze events have proven to be ideal zones for identifying species with variable climate adaptation. This paper will identify these regions around the globe and show how these regions offer distinct advantages in selecting for abiotic and biotic stresses and thus resiliency to changing climate. Programs located in these regions have the advantage of exposure to alternating extreme warm and cold temperatures, drought and flood conditions, and a multitude of biotic stresses. Examples are successes and constraints in moving cool-season species into warmer climates and tropical species into cooler climates. We present a rationale for which direction of species movement (tropical to temperate vs temperate to tropical) may be more likely to encounter success and why. Specific plant attributes that contribute to climate resiliency will be identified and described. The ability to identify small changes in genetic photoperiod responses in these regions, where daily changes are less than 1.5 m, is illustrated as a further advantage when the objective is the development of earlier or later maturity. These regions also provide suitable environments for pests from tropical and temperate areas, including diseases, nematodes, and insects, providing desirable field environments for screening and genetic improvement through cycles of recurrent selection. A discussion of the reproduction method is included to illustrate the need to accomplish seed production of these species in other zones to produce higher yields of high-quality seed.

Introduction
Climate change can have major impacts on adaptation of forage species to ecozones around the world. An example would be peninsular Florida where two successive winters with minimum low temperatures characterized as “100-year freeze events” occurred in the mid 1980’s. The record low temperature for Gainesville, FL of -12.2° C was recorded in January 1985. However, in the decade since 2010 the lowest temperature has been -4.7° C, and number of freeze events per winter season has dramatically decreased. Both winter minimum and number of freeze events are determining factors for survival of perennial warm season grasses and legumes in transitional climate zones.

Limpograss [Hemaerthria altissima Poir (Stap & CE Hubb)] has shown moderate leaf tissue tolerance to light frost and freeze events. This ability to remain photosynthetically active through the winter months in the southern part of peninsular Florida, along with the finding that limnograss has a slower rate of decline in digestibility with age (Quesenberry et al., 2018), has resulted in a dramatic shift away from hay production to use of stockpiled limnograss for winter pastures in South Florida.

Cool-season legumes have not been widely utilized in pastures in the southeast USA, primarily because photoperiod dormancy of cultivars developed further north limits late winter – early spring growth. However, the ability to select for reduced dormancy in red clover (Trifolium pratense L.) and white clover (Trifolium repens L.) has resulted in low dormancy cultivars that are making an impact in beef forage/livestock systems in Florida and the Coastal Plains of the USA (Quesenberry et al., 2012, 2015).

Likewise, the development of annual ryegrass (Lolium multiflorum Lam.) with variable maturity responses and high levels of foliar leaf disease resistance has increased the use of this species in beef and dairy forage systems in the lower southeastern USA (Kenworthy et al., 2016; Prine, 2001; Prine et al., 2002). Furthermore, the development of annual cereal crops [oat
(Avena sativa L.), rye (Secale cereale L.), and wheat (Triticum aestivum L.) with reduced winter dormancy and high levels of foliar disease resistance have resulted in increased use as winter annual grazed cereal crops in the SE USA.

Global latitudes between 27 and 31° N or S offer unique breeding opportunities and variable dormancy response selection opportunities. The low daily rate of change in day length in late winter to early spring, and similarly in late fall and early winter, enables breeders to readily select for small differences in dormancy response (Deren and Quesenberry 1989; Kenworthy et al., 2016; Quesenberry et al., 2015a, Williams, et al., 2008). These latitudes typically also experience tropical and temperate plant disease and insect pests, providing ideal locations for pest resistance breeding programs (Quesenberry et al., 2010, 2015). Likewise, locations in these latitudes often have winter minimum temperatures varying around 0°C that can allow for the selection of differences in leaf tissue damage by light to moderate frost/ freeze events (Acuna et al., 2009; Breman et al., 2008) and winter survival of warm-season legume species (Carvalho and Quesenberry, 2009). It has also been demonstrated that in these latitudes, the expression of apomixis may vary toward the end of the growing season (Ríos et al., 2013). This introductory paper will provide specific examples of temperate/tropical transition zones are ideal hotspots for identifying and breeding forages with climate resiliency.

Results

Dormancy Responses

Maximum summer day length at near 30° N (e.g. Gainesville, FL) or S are about 14 hr, and the rate of day length change in late winter and early spring is about 1 min and 45 sec (12.25 min per week) at the spring equinox. In contrast, the longest summer day at near 45° N (e.g. St. Paul, MN) is 15 hr and 37 min and the rate of day length change is 3 min and 10 sec (22.17 min per week) spring equinox. With the normal variations in plant phenology caused by temperature, rainfall, and other factors, it becomes apparent that the ability to segregate out small differences in dormancy is greater at the lower latitudes.

Since 1997 the annual ryegrass breeding program at the University of Florida has developed and released 25 cultivars licensed for production and distribution to the major forage seed production companies in the USA. Seed sales reported on exclusively licensed UF/IFAS annual ryegrass cultivars averaged over 2016 to 2019 were just over 12.5 million kg per year. This represents about 15% of the reported annual ryegrass seed production in the USA and approaches 50% of the proprietary variety seed sales. The success of these cultivars can be attributed to selection for variable spring DM production due to early, mid and late dormancy responses and selection for the high level of foliar disease resistance (Prine, 2001).

Red clover has historically been bred and utilized in temperate zones. Beginning in the 1980s, a selection program for early spring production and pest resistance in red clover was conducted at the University of Florida. This program has resulted in the release of four cultivars and developing a 4X germplasm with adaptation to the lower SE USA. Figure 1 illustrates the range of dormancy among these populations, developed at the University of Florida, compared to the mid-dormancy cultivar ‘Kenton’. ‘Southern Belle’, ‘Cherokee’, and FL4X are low dormancy, whereas ‘Barduro’ has dormancy between Kenton and Southern Belle. The new FL24D cultivar is the most non-dormant cultivar of red clover we have produced.

The work developing a reduced dormancy red clover for the lower SE USA followed the example of other research at the University of Florida that developed ‘Osceola’ white clover (Balensperger et al., 1984). The germplasm of white clover has been divided into small, intermediate, and large or Ladino categories. In Florida, the ladino types show little flowering before warm summer temperatures and summer rains in June, reducing plant vigour and growth. Conversely, intermediate types flower in late winter/early spring and thus have limited yields. Crossing and selection in N. Florida resulted in developing the cultivar ‘Osceola’ white clover (Balensperger et al., 1984). The germplasm of white clover has been divided into small, intermediate, and large or Ladino categories. In Florida, the ladino types show little flowering before warm summer temperatures and summer rains in June, reducing plant vigour and growth. Conversely, intermediate types flower in late winter/early spring and thus have limited yields. Crosses and selection in N. Florida resulted in the cultivar ‘Osceola’ white clover with traits that fall between intermediate and ladino types. For the decades of the 1990s through 2010, Osceola was utilized throughout the southern and transitional zone states of the USA as a popular and important cultivar.

Alfalfa (Medicago sativa L) had historically been considered to be poorly adapted to the lower SE USA. However, a long-term program of recurrent mass selection under field conditions at Gainesville, FL, resulted in ‘Florida 77’ releasing with good production and moderate persistence in N. Florida (Horner and Ruelke, 1981). Additional selection resulted in the release of the cultivar ‘Florida 99’. This germplasm pool has been the basis of other breeding efforts that have resulted in the development of several alfalfa cultivars adapted across the Coastal Plains and lower SE USA. New breeding efforts began at the
University of Florida by testing germplasm from other subtropical pools and crossing with Florida 99 background (Acharya et al., 2020). A potential new alfalfa cultivar (UF_AP_2015) selected for increased yield and persistence in the SE USA is currently under final stage testing for release.

**Pest Resistance Responses**

Climatic conditions in these temperate/tropical transition zones are ideal laboratories for plant pest problems. This often allows breeders to progress screening for disease resistance using simple field phenotypic responses. An example of this is the annual ryegrass breeding program in the Agronomy Department at the University of Florida. North Central Florida typically experiences the onset of crown rust (*Puccinia coronata* Corda) and grey leaf spot (*Pyricularia oryzae* Cavara) on annual ryegrass in late winter to early spring. Table 1 shows that cultivars developed in Florida (Experimental FL4XR16, ‘Attain’, ‘Big Boss’, and ‘Jumbo’) have superior crown rust and grey leaf spot resistance than cultivars developed in more temperate climates (‘Marshall’ and ‘Lonestar’).

Soil-borne pests such as plant-parasitic nematodes are also more likely to be present in these temperate/tropical transition zones. Little variability exists in temperate legume germplasm for resistance to most of these nematodes (Kouame et al., 1997). Cultivars of alfalfa, red clover, and white clover developed in Florida have now been released with moderate to high resistance levels to root-knot nematodes (*Meloidogyne* spp.) (Horner and Ruelke, 1981; Quesenberry et al., 2012; Quesenberry et al. 2015). We have shown that in red clover, recurrent selection for low galling and egg mass production in response to infestation with *Meloidogyne* spp. has identified quantitative genes that result in a reduction in all life cycle stages (root penetration, larvae maturation, and fecundity) of the nematode (Call et al., 1997). This research resulted in the development and release of Southern Belle red clover with high resistance levels to root-knot nematodes. Subsequent research in white clover produced similar findings (Acharya et al., 2011) and resulted in the development and release of ‘Ocoee’ root-knot nematode-resistant white clover (Quesenberry et al., 2015). Table 2 shows that in both red clover and white clover, significant reductions have been achieved in plant responses to *Meloidogyne* spp. We have also identified variability for response to root-knot nematodes in aeschynomene (Quesenberry et al., 1985) and *Desmodium* spp. (Quesenberry and Dunn, 1987).

**Frost/freeze Responses**

As mentioned above, a major factor influencing selection for moving tropical species into temperate transitional zones is genetic variability for leaf tissue tolerance to mild frost and freeze events and overall plant resistance to winter, killing from even colder temperature events. Because our winters in Florida frequently have these marginal frost/freeze events, we have been able to identify trait diversity in limpograss and bahiagrass (*Paspalum notatum* Flugge) (Breman et al., 2008). Additionally, these “mild” winter minimum temperatures have allowed us to identify variability for winter survival in rhizoma perennial peanut *Arachis glabrata* Benth (Williams et al., 2008) and pintoi perennial peanut (*Arachis pintoi*. Krapov. & W.C.Gregory) (Carvalho, at al., 2009). Generally, the tropical perennial species that have been successfully adapted to temperate climates have been those with below-ground storage organs (rhizomes), e.g. bermudagrass and rhizoma perennial peanut. Major issues encountered with the adaptation of temperate species to warm climates have been a lack of resistance to a new disease, insect and nematode pests, and dormancy modifications described above. Success has been made in both directions of movement, but we suggest that temperate to tropical movement is likely to be a more challenging breeding objective.

**Conclusions**

In a temperate/tropical transition zone environment within 27 and 31°N latitude, breeding and selection has successfully moved cool-season species into warmer climates and adapted tropical species into cooler climates. Furthermore, we have attempted to identify specific attributes (e.g. growth habits, dormancy responses, pest resistances, methods of reproduction, etc.) of species that contribute to climate resiliency. The papers which follow will amplify examples of temperate and tropical grasses and legumes, and issues related to seed production.
References


**Table 1:** Disease responses of annual ryegrass cultivars and experimental lines at the University of Florida.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Crown Rust</th>
<th>Grey leaf spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL4X R16</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Attain</td>
<td>2.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Big Boss</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Jumbo</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Lonestar</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Marshall</td>
<td>8.3</td>
<td>.</td>
</tr>
<tr>
<td>Average</td>
<td>4.0</td>
<td>2.4</td>
</tr>
<tr>
<td>LSD (P=0.05)</td>
<td>2.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Table 2:** Response of red and white clover cultivars to three root knot nematode species

<table>
<thead>
<tr>
<th>Entry</th>
<th>M. arenaria</th>
<th>M. incognita</th>
<th>M. javanica</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Galls†</td>
<td>Eggs</td>
<td>Galls</td>
</tr>
<tr>
<td>Kenstar</td>
<td>5.0 a‡</td>
<td>5.0 a</td>
<td>3.9 a</td>
</tr>
<tr>
<td>Southern Belle</td>
<td>3.3 b</td>
<td>3.3 b</td>
<td>2.3 b</td>
</tr>
<tr>
<td>FL 4X</td>
<td>3.0 b</td>
<td>2.8 b</td>
<td>2.4 b</td>
</tr>
<tr>
<td>Barduro</td>
<td>2.3 b</td>
<td>1.9 b</td>
<td>2.3 b</td>
</tr>
<tr>
<td>Osceola</td>
<td>3.9 x</td>
<td>3.1 x</td>
<td>3.9 x</td>
</tr>
<tr>
<td>Ocoee</td>
<td>2.6 y</td>
<td>2.4 y</td>
<td>1.6 y</td>
</tr>
</tbody>
</table>

†0 = no galls or egg masses per plant; 1 = 1 or 2; 2 = 3–10; 3 = 11-30; 4 = 31–100; 5 = more than 100.

‡Means within a column followed by the same letter are not significantly different, Duncan’s Multiple Range Test, P = 0.05.

Note that the white clover cultivars Osceola and Ocoee were evaluated in a different experiment from the red clover cultivars, thus a different set of letters are used to denote statistical differences.
Figure 1: Percentage flowering of red clover cultivars over time in the spring in Gainesville, FL.
Breeding forage annual ryegrass at the University of Florida

Kenworthy¹, K.E., Reith¹, P.E., Rios¹, E.F, Blount², A.R., van Santen¹ E. and Quesenberry¹, K.H.
³University of Florida, Agronomy Department, Gainesville, FL, USA
²University of Florida, NFREC, Quincy, FL, USA

Abstract
Peninsular Florida essentially has a “Temperate Winter” and a “Tropical Summer” presenting unique challenges for genetic improvement of plants. These challenges include identifying cool-season species with sufficient disease resistance to survive and produce in the warm season. The climate and disease pressures of North Florida have proven ideal for field screening and breeding for improved disease resistance and the latitude is ideal for making selections that result in incremental changes in day length responses associated with flowering. Annual ryegrass (Lolium multiflorum Lam) is widely used as a desirable forage to provide winter grazing in the southeastern United States (U.S.) and as a cover crop in the midwestern U.S. The University of Florida annual ryegrass program has been actively developing cultivars since the mid-1980s. Phenotypic recurrent mass selection has been the primary method to develop disease resistant cultivars with variable maturities. Manipulation of ploidy has been shown to be another important tool for genetic improvement to provide novel cultivars. The program has released 27 annual ryegrass cultivars (23 are currently on the market), of which 12 are tetraploid and 15 are diploid. All these cultivars have been licensed by the Florida Foundation Seed Producers, Inc. to commercial companies in the Pacific Northwest, USA. Cultivars that have particular commercial success include the tetraploids ‘Attain’, “Big Boss’, ‘Jumbo’ and ‘Prine’; and diploids, ‘Fria’ and ‘Winterhawk’. Annual ryegrasses from the University of Florida are high yielding and have a wide range of maturity dates. A 2017 release, ‘FrostProof’, has enhanced cold tolerance. Future research will be directed towards adaptation to global climate changes that include enhanced disease resistance, increased drought resistance and adaptability to erratic temperature changes. Genomic selection tools are being evaluated to enhance progress in the breeding program. Several cultivars are planned for future release.

Introduction
Annual ryegrass is widely used for cool-season forage production in the southeastern United States (Wright et al., 2012). Date of planting for annual ryegrass may vary from late September to early December. Ryegrass can be seeded on a clean prepared seedbed, often seeded in a mixture with rye (Secale cereal L.) or oat (Avena sativa L.). Annual ryegrass may also be overseeded on fall dormant C4 tropical grasses such as bahiagrass (Paspalum notatum Flugge), or bermudagrass (Cynodon dactylon L). Overseeding establishment is impacted by onset of dormancy of these C4 grasses (Wright et al., 2012). Producer decisions for time of fall planting involve a trade-off between the need for the higher nutritive value provided by early annual ryegrass production versus competition for light and water from the perennial C4 grasses. Early annual ryegrass production can be critical for grazing animal forage quantity and quality (Wright et al., 2012).

Conversely, late spring frosts and freezes, and spring droughts may delay production of warm-season grasses, creating a demand for late-season forage production from annual ryegrass (Glidewell, 2010). However, continued production of later-maturing annual ryegrasses may delay early production of perennial summer pastures and reduce first-grazing yields (Hancock, 2014). Annual ryegrass is also frequently grown with cool-season forage legumes such as crimson clover (Trifolium incarnatum L.) or red clover (T. pratense L). Mixtures of annual ryegrass and legumes with variable dormancy responses can extend the period of availability of forage and level some of the peaks and valleys in production that may occur with warm-season monocultures. Our location at 29.6° N has small daily changes in day length and enhances the ability to select for variability in dormancy which is a critical component in developing climate resilient forages.
Ploidy level increases in plants usually result in greater nuclear and cell volume and, in many species, larger plant parts, particularly leaves, stems, flowers, and seeds (Burnham, 1962). Commercial success of polyploidy in cultivar development has primarily been limited to some floriculture crops and to certain forage species. Red clover, particularly in Europe (Taylor and Quesenberry, 1996), and annual ryegrass are species with commercial success of tetraploid cultivars. Large year effects and cultivar × year effects have been observed in multilocation annual ryegrass cultivar evaluations (Kenworthy et al., 2016; Redfearn et al., 2005). Blount and Prine (2012) noted that “Recent yield data suggests that newer tetraploid cultivars are at least equal to, and may have some yield advantage over, their diploid relatives.” Our program recently reported ploidy characterization of 139 annual ryegrass accessions obtained from the USDA GRIN collection of annual ryegrass, plus 15 Florida experimental lines and 13 commercial cultivars (Rios et al., 2015). Only 16% (27 out of 167) of accessions evaluated were tetraploid and these were all breeding lines or cultivars since tetraploid annual ryegrass does not occur naturally.

The subtropical climate of north Florida and the lower Coastal Plains of the USA is characterized by increasing daily temperatures and relative humidity as spring progresses toward summer. This creates ideal conditions for a number of diseases of annual ryegrass including crown rust (Puccinia coronata Corda), gray leaf spot (Pyricularia grisea Sacc.) and bipolaris leaf disease (Bipolaris stenospora Drechs.) Shoemaker). These diseases limit production of annual ryegrass. ‘Gulf’ annual ryegrass was released by Texas A&M University in 1958 (Weihing, 1963) as an early-maturing cultivar resistant to crown rust and has dominated the commodity (uncertified) annual ryegrass trade for many years. With the evolution of races of crown rust over time, Gulf has become susceptible to present day strains of crown rust, illustrating the need for continued development of new disease resistant cultivars to provide climate resiliency.

**Breeding Program Methods**

The primary breeding objectives of our program have been to develop annual ryegrass cultivars with adaptation to global climate changes including enhanced disease resistance, increased drought resistance, high biomass production, and diverse maturities. Historically, the breeding method has been phenotypic recurrent mass selection, relying on natural infestations of foliar diseases for selection. There has always been a focus on developing populations with early, mid, and late dormancy facilitated by selection at our subtropical latitude. Dr. Gordon Prine assumed primary responsibility for the program in the mid-1980s, and the first release from the program was ‘Surrey’ in 1989 (Prine, et al., 1989). In cooperation with German scientists, Dr. Prine developed tetraploid annual ryegrass from his breeding program. Selection and development of superior tetraploid cultivars became a significant focus in the 1990s.

**Cultivar Development and Releases**

During the period 1997 to 2006, the UF/IFAS annual ryegrass breeding program released 11 tetraploid cultivars of which 10 are currently in production. Four of these had annual production between 1.69 and 3.65 million kg of seed in 2020. These four are ‘Attain’ (released in 2002), ‘Big Boss’ (released in 2004), ‘Jumbo’ (Prine et al., 2002), and ‘Prine’ (released in 2001). For the five year period of 2016 to 2020 reported seed sales of these 10 tetraploid cultivars from our program averaged almost 10 million kg per year which at a seeding rate of 28 kg ha⁻¹ would plant over 350,000 ha of annual ryegrass per year (Personal communication, Mr. Jim Holm, Licensing Agent, Florida Foundation Seed Producers, Inc.).

During this same period, 16 diploid cultivars were released of which 12 remain in production. The non-proprietary annual ryegrass seed market is dominated by the diploid “Gulf” (Oregon common). Only one of our diploid cultivars (Winterhawk) has exceeded 1.0 million kg annual production averaged over these five years, and diploid seed sales of our releases represented only about 20% of the total seed sales of our released cultivars. Nevertheless, based on total seed sales reported, total potential hectares that could be seeded from all 2X and 4X cultivars from our program, averaged over the five years, would be over 455,000. These production data suggest that tetraploid annual ryegrass may demonstrate greater producer acceptance and possible stronger climate resiliency.

The 22 active cultivars mentioned above have been licensed to most of the major annual ryegrass seed production companies in the Pacific northwest of the USA. After 2006, the breeding program has been directed by Dr. Kevin Kenworthy at Gainesville, with additional selection and cultivar development by Dr. Ann Blount at the NFREC, Marianna, FL. Since that time four additional populations (three tetraploid and 1 diploid) have been released and are just now beginning to make an impact in the marketplace.
Cultivar Characteristics

Annual ryegrass cultivar DM yield evaluation experiments generally show significant year and year by location interactions. Table 1 shows dry matter yield performance of FL4XR16, our newest tetraploid annual ryegrass cultivar, compared to some other currently popular 2X and 4X cultivars, when grown at four locations over three years. This new population had the highest index score (Yield in the top statistical group at a location) compared to Nelson (developed at Texas A & M University, Nelson, et al., 2011), Jackson (developed at Mississippi State University, Watson, at al., 1990) and Big Boss and Attain (widely grown cultivars developed at UF/IFAS). These data illustrate the value of continued recurrent phenotypic selection in improving overall cultivar performance in an era of continuing climate changes. This new cultivar shows regional yield stability an indicator climate resiliency.

As discussed previously, variability in spring dormancy/maturity and foliar disease resistances are traits that contribute to overall usefulness of cultivars in livestock production success. Table 2 shows that FL4XR16 is among the earlier maturing populations evaluated. It generally had the highest level of resistance to crown rust and grey leaf spot disease or was not significantly different from the most disease resistant line evaluated. High levels of disease resistance are critical for year to year and location to location stability and demonstrate climate resiliency.

Conclusion

Annual ryegrass is an important component of forage/livestock systems in the transition climate zone of the USA. With an increasing emphasis on cover crops and crop rotations for annual grain and legume crops, other uses of annual ryegrass are increasing in importance. With the projected northward movement (in the northern hemisphere) of crop hardiness zones with climate change, and our selection of more winter hardy populations of annual ryegrass, this species should find additional areas of use. Breeding and selection for climate resiliency will continue to be of importance in the future.

The location of the UF breeding program, on the southern edge of North America, tempered by surrounding oceans is an ideal location for field selection of populations with variable dormancy responses. Combinations of cool temperate winters and warm humid springs with consistent foliar disease epidemics allows for selection of high levels of resistance to these pathogens as demonstrated in evaluation data of some of recent cultivar releases. Identification of these combinations of cultivars with variable dormancy and maturities with high levels of foliar disease resistance and good seed production characteristics will continue to supply the USA market with climate resilient annual ryegrasses in the future. Licensing partnerships with multiple commercial seed production companies in the Pacific Northwest of the USA have been effective in supplying the seed demand throughout the USA. Continued development of new populations is expected along with promotion of the value of improved cultivars vs “common” annual ryegrass to increase the demand in the future.

References


### Table 1: Total annual dry matter yields of FL4XR16 annual ryegrass and selected comparison cultivars over multiple locations and years

<table>
<thead>
<tr>
<th>Entry*</th>
<th>2016-17</th>
<th>2017-18</th>
<th>2018-19</th>
<th>2016-19</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marianna, FL</td>
<td>Hague, FL</td>
<td>Tifton, GA</td>
<td>Marianna, FL</td>
</tr>
<tr>
<td>FL4XR16</td>
<td>8060</td>
<td>13037</td>
<td>12046</td>
<td>10929</td>
</tr>
<tr>
<td>Nelson</td>
<td>8570</td>
<td>11488</td>
<td>11370</td>
<td>10086</td>
</tr>
<tr>
<td>Big Boss</td>
<td>7771</td>
<td>10519</td>
<td>11201</td>
<td>10616</td>
</tr>
<tr>
<td>Marshall</td>
<td>7296</td>
<td>10947</td>
<td>11907</td>
<td>9951</td>
</tr>
<tr>
<td>Attain</td>
<td>7534</td>
<td>10582</td>
<td>11056</td>
<td>10791</td>
</tr>
<tr>
<td>Lonestar</td>
<td>6895</td>
<td>8618</td>
<td>11370</td>
<td>9578</td>
</tr>
<tr>
<td>Jackson</td>
<td>7558</td>
<td>11836</td>
<td>11280</td>
<td>9940</td>
</tr>
<tr>
<td>FrostProof</td>
<td>7118</td>
<td>.</td>
<td>10404</td>
<td>9772</td>
</tr>
<tr>
<td>Average</td>
<td>7147</td>
<td>10892</td>
<td>10926</td>
<td>9694</td>
</tr>
<tr>
<td>Maximum</td>
<td>8598</td>
<td>13083</td>
<td>12276</td>
<td>11508</td>
</tr>
<tr>
<td>Minimum</td>
<td>5380</td>
<td>5022</td>
<td>9713</td>
<td>7015</td>
</tr>
<tr>
<td>LSD (P=0.10)</td>
<td>925</td>
<td>2020</td>
<td>982</td>
<td>1036</td>
</tr>
</tbody>
</table>


*1LSD values from Hague, and Citra, FL are at P=0.05
Table 2: Disease ratings and maturity dates of FL4XR16 annual ryegrass and selected commercial cultivars.

<table>
<thead>
<tr>
<th>Entry*</th>
<th>CR - AFRU</th>
<th>GLS - AFRU</th>
<th>Maturity</th>
<th>GLS - AFRU</th>
<th>Maturity</th>
<th>GLS - PSREU</th>
<th>Maturity</th>
<th>GLS - AFRU</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL4XR16</td>
<td>1.7†</td>
<td>1.0</td>
<td>6-Mar</td>
<td>2.3</td>
<td>5-Apr</td>
<td>3.0</td>
<td>2.3</td>
<td>20-Mar</td>
<td></td>
</tr>
<tr>
<td>Attain</td>
<td>2.7</td>
<td>1.7</td>
<td>29-Mar</td>
<td>4.0</td>
<td>11-Apr</td>
<td>5.7</td>
<td>3.7</td>
<td>5-Apr</td>
<td></td>
</tr>
<tr>
<td>Big Boss</td>
<td>3.0</td>
<td>2.0</td>
<td>21-Mar</td>
<td>4.7</td>
<td>11-Apr</td>
<td>7.0</td>
<td>4.7</td>
<td>2-Apr</td>
<td></td>
</tr>
<tr>
<td>Jackson</td>
<td>4.7</td>
<td>2.7</td>
<td>29-Mar</td>
<td>4.3</td>
<td>5-Apr</td>
<td>5.6</td>
<td>3.7</td>
<td>10-Apr</td>
<td></td>
</tr>
<tr>
<td>Jumbo</td>
<td>2.3</td>
<td>2.3</td>
<td>5-Apr</td>
<td>4.0</td>
<td>16-Apr</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>Lonestar</td>
<td>6.0</td>
<td>3.0</td>
<td>29-Mar</td>
<td>.</td>
<td>.</td>
<td>7.3</td>
<td>5.3</td>
<td>5-Apr</td>
<td></td>
</tr>
<tr>
<td>Nelson</td>
<td>2.7</td>
<td>2.7</td>
<td>3-Apr</td>
<td>3.7</td>
<td>16-Apr</td>
<td>6.0</td>
<td>4.7</td>
<td>15-Apr</td>
<td></td>
</tr>
<tr>
<td>Marshall</td>
<td>8.3</td>
<td>2.7</td>
<td>5-Apr</td>
<td>3.0</td>
<td>13-Apr</td>
<td>4.7</td>
<td>3.0</td>
<td>15-Jun</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>4.0</td>
<td>2.4</td>
<td>.</td>
<td>3.7</td>
<td>.</td>
<td>5.0</td>
<td>3.7</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>8.3</td>
<td>4.3</td>
<td>5-Apr</td>
<td>8.0</td>
<td>25-Apr</td>
<td>9.0</td>
<td>8.0</td>
<td>15-Apr</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>1.7</td>
<td>1.0</td>
<td>4-Jan</td>
<td>2.0</td>
<td>1-Feb</td>
<td>2.0</td>
<td>1.3</td>
<td>15-Jan</td>
<td></td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>2.1</td>
<td>1.5</td>
<td>1.2</td>
<td>1.2</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


†CR = Crown Rust caused by Puccinia coronata Corda; GLS = Grey Leaf Spot caused by Pyricularia oryzae Cavara;

‡Maturity determined by the date of first anthesis.

§Rated on a scale of 0 to 10 where 0 = no disease and 10 = 100% coverage. Bolded values were in the top statistical group.
Moving warm-season forage bermudagrass (*Cynodon* sp.) into temperate regions of North America

Anderson, W.F. ¹; Baxter, L.²; Hancock, D.³; Gates, R.N.⁴; Rios, E.F.⁵.

¹Research Geneticist USDA/ARS, Tifton, GA
²Forage Extension Specialist, Crops and Soils Science Dept., University of Georgia, Tifton, GA
³3Center Director USDA/ARS US Forage Dairy Research Center, Madison, WS
⁴Agriculture & Natural Resources Agent, Whitfield County Extension, College of Agricultural and Natural Resources, University of Georgia
⁵Assistant Professor, Forage Breeding and Genetics, Agronomy Department, University of Florida, Gainesville, FL

Key words: Breeding; Bermudagrass; cold tolerance

Abstract
Warm-season (C₄) perennial grasses are grown over millions of hectares in the Southeastern United States. These grasses produce optimal growth at 30 to 38°C diurnal temperature. Bermudagrass (*Cynodon* sp.) has been adopted as the preferred forage for many livestock and hay producers. Compared to other native and introduced warm-season perennial grass species, improved bermudagrass varieties produce high biomass with enhanced digestibility for ruminant grazing or feed. Until the 1930’s pastures in the region consisted of unimproved ‘common’ bermudagrass (*Cynodon dactylon* (L.) Pers.) that had been introduced earlier. However, in the early 20th century, new germplasm, including stargrass (*C nlemfuënsis* Vanderyst) was collected, primarily from Africa. This germplasm provided a source for major improvements in yield and digestibility. Unfortunately, stargrass is not cold tolerant, limiting it to regions between 30°N and 30°S. Intercrossing of *C. nlemfuënsis* with *C. dactylon* has produced highly successful cultivars, such as Tifton 85, which can survive at northern latitudes of at least 35°. However, there has been a desire to extend adaptation further north into the warm-season/cool-season grass transition zone. This would require a combination of breeding to improve cold tolerance in clonally-propagated varieties and development of seeded varieties that could be re-seeded following extremely cold winters. Earlier work at Oklahoma State University indicated that some cultivars had significantly different tolerance to freeze. Screening the Tifton, GA, USA core collection of 175 accessions in a northern, high-altitude location, has identified germplasm with promising cold tolerance. A breeding line (Tifton 79-16) had significantly higher yields at the northern Georgia location than the cold tolerant cultivar (Tifton 44). A number of plant introductions had higher yields as well.

Introduction
As the overall climate throughout the world changes to warmer, drier conditions, it will be important to identify forages with greater adaption. In many parts of the temperate world, cool-season grasses predominate due to adaptation to colder temperatures (5°C to 25°C). However, warm-season grasses that produce biomass using C₄ photosynthesis are much more productive during the hot, dry months of summer. They thrive in temperatures between 20°C to 35°C and are much more drought tolerant (Moore et al., 2004). In the transition zones between warm season and cold season perennial grasses of North America, C₄ grasses can maintain productivity while C₃ grasses are transitioning to a reproductive stage with minimal vegetative growth. For this reason, warm season grasses could replace a portion of the pastures at latitudes greater than 35°. Worldwide, there are several warm-season forage grass species. Some of these perennial grasses have adapted to more northern climates such as upland switchgrass (*Panicum virgatum* L.). However, bermudagrass (*Cynodon* sp.) is considered the most valuable C₄ forage in the southern United States (Taliaferro et al., 2004) due to its ability to be used for grazing, green chop, or stored forage production. Cultivars have been developed...
that produce over 20 Mg/ha dry matter per year with high forage quality (Burton et al., 1993). Adaptation of bermudagrass to the transition zone is limited due to its intolerance of extended freezing temperature during winter. Since the most productive bermudagrass cultivars are propagated vegetatively, the expense of reestablishment on a yearly or biannual basis is prohibitive.

*Cynodon dactylon* L has adapted to colder climates and landraces have been collected in many temperate areas (Taliaferro et al., 2004). The cold tolerance is primarily due to the presence of rhizomes that are underground structures that can survive cold winters. However, stargrass (*C. nlemfuënsis* Vanderyst) is more productive and has better nutritive value. This species generally lacks rhizomes and does not survive above 30° latitude. Developing cold-tolerant and productive forage bermudagrass cultivars will require screening and selecting parental lines in latitudes higher than 30.

Work on cold tolerance in turf-type and forage-type bermudagrass has been performed at Oklahoma State University. A laboratory freeze screening method was developed to assist in evaluating genotypes (Anderson et al., 1993; Anderson and Taliaferro 1995). Studies were conducted in the laboratory with plant material being established and acclimated in growth chambers. These cloned plants were then subjected to a range of temperatures in a freeze chamber. The laboratory evaluations corresponded well with field observations and has given geneticists and plant physiologists useful information on characteristics associated with freeze tolerance in turfgrasses. Cold tolerant turf-types were identified using this technique (Anderson et al., 2002, 2007; Munshaw et al., 2006). Most of the cold tolerant lines can be traced to species and germplasm originating from northern climates. Laboratory results from Oklahoma State University resulted in significant freeze tolerance by cultivars developed in Oklahoma (Fig. 1). Tolerant cultivars were developed from parents originating from temperate origins including ‘Ozark’, developed from a cross between Coastal and an accession from Afghanistan (PI 253302). ‘Midland 99’, ‘Goodwell’, and ‘Hardie’ all have genetic background from Afghanistan, as well as some other accessions from temperate climates.

![Figure 1: Freeze tolerance of forage bermudagrass cultivars compared to Midland (P = 0.05). (Anderson and Wu 2011). (Negative values reflex less cold tolerance than Midland)](image)

Other than this, relatively little work has been done on forage cultivars or germplasm. More work to screen larger numbers of germplasm was needed. For this purpose, a core collection of 175 accessions was evaluated at Blairsville, GA, US over two years.

**Research on cold tolerance in forage bermudagrass**

Three replications of the entire core collection were randomized in the field in the mountains of North Georgia at Blairsville, GA, (34.84 Lat., -83.93 Long., 590 m Elev.) with average minimal temperatures of -3.9 °C. One plant (8 cm pot) was transplanted on June 28, 2007 for each experimental unit, allowed to establish and clipped in September. Emergence in the spring was rated on a 0 to 5 scale (0 = not emerged; 1 = 1-5 green stems or stolons; 2 = 6-15; 3= 16-30; 4 = 30-50; 5 = greater than 50 stems or stolons) on April 15, 2008 and May 11, 2009. Percentage plot cover was recorded on April 30, 2008 and June 29, 2009. Plant height (to last fully expanded leaf) was recorded May 12 and June 6, 2008 and again on August 6, 2008. Plant diameter was measured June 6, 2008. Plots were clipped June 30, 2008 and June 29, 2009, leaving a 5 cm stubble. In 2008, the entire above ground plot was harvested since there was variation in cover for individual plots. Material was dried at 50°C and weighed to determine dry mass. Herbage accumulation was calculated in 2008 by determining the dry weight for the area of the harvested plot (Y = A*dry matter weight of plot) where area (A). Yield was determined in 2009 by clipping a 929 cm² area
in the centre of the plot. Height of regrowth was recorded August 6, 2008 and August 5, 2009. Dry plant material from 2008 was ground with a Wiley Mill through a 1-cm screen. In vitro dry matter digestibility (IVDMD) and fiber components were determined by using previously calibrated NIRS equations (Barton and Windham, 1988).

Results
Due to the cold winters of 2008 and 2009, 31 entries did not survive. Of the remaining 142 entries 20 accessions had a higher average yield than Tifton 44. A few exhibited greater IVDMD than Tifton 44 including PI 290660. Among the most cold-tolerant lines from Blairsville, PI 225809 and PI 291724 might be used in breeding to improve seed set, germination and cold tolerance (Table 1). Emergence on these lines were similar to Tifton 44 and Coastal. Most had fine texture leaves and stems and one line (PI 290660) had superior IVDMD.

Table 1: Cultivar name or plant introduction number (PI), Cynodon species, and mean performance for spring emergence, plant height (cm), herbage accumulation per year and average for two years (kg/ha), leaf and stem texture, and IVDMD for 13 bermudagrass genotypes grown in Blairsville, GA between 2007 and May 2009.

<table>
<thead>
<tr>
<th>Entry/PI</th>
<th>Species</th>
<th>Emergence Rating</th>
<th>Pl. height (cm)</th>
<th>Yield kg/ha</th>
<th>Stem texture</th>
<th>IVDMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tifton9-16</td>
<td>C. dactylon</td>
<td>3.3</td>
<td>7/17/2009</td>
<td>9841</td>
<td>10482</td>
<td>10012</td>
</tr>
<tr>
<td>293606</td>
<td>C. dactylon</td>
<td>2.7</td>
<td>16.3</td>
<td>6516</td>
<td>11400</td>
<td>8959</td>
</tr>
<tr>
<td>290660</td>
<td>C. dactylon</td>
<td>2.3</td>
<td>7.5</td>
<td>7599</td>
<td>10074</td>
<td>8837</td>
</tr>
<tr>
<td>289917</td>
<td>C. dactylon</td>
<td>4.2</td>
<td>12.7</td>
<td>8732</td>
<td>8820</td>
<td>8775</td>
</tr>
<tr>
<td>289748</td>
<td>C. polevansii</td>
<td>3.3</td>
<td>10</td>
<td>7823</td>
<td>9537</td>
<td>8680</td>
</tr>
<tr>
<td>212293</td>
<td>C. dactylon</td>
<td>3.8</td>
<td>13.7</td>
<td>5720</td>
<td>11114</td>
<td>8417</td>
</tr>
<tr>
<td>206553</td>
<td>C. dactylon</td>
<td>3.7</td>
<td>13.3</td>
<td>7037</td>
<td>9250</td>
<td>8144</td>
</tr>
<tr>
<td>225809</td>
<td>C. spp</td>
<td>1.7</td>
<td>14.3</td>
<td>7202</td>
<td>8784</td>
<td>7992</td>
</tr>
<tr>
<td>291575</td>
<td>C. bradleyi</td>
<td>2.2</td>
<td>12.7</td>
<td>6589</td>
<td>9393</td>
<td>7991</td>
</tr>
<tr>
<td>292544</td>
<td>C. dactylon</td>
<td>3.7</td>
<td>11.7</td>
<td>6206</td>
<td>9393</td>
<td>7800</td>
</tr>
<tr>
<td>Tifton 44</td>
<td>C. dactylon</td>
<td>3.2</td>
<td>14.3</td>
<td>4504</td>
<td>9465</td>
<td>6984</td>
</tr>
<tr>
<td>Coastal</td>
<td>C. dactylon</td>
<td>2.6</td>
<td>14.7</td>
<td>3572</td>
<td>8497</td>
<td>6035</td>
</tr>
<tr>
<td>Tifton 85</td>
<td>C. spp</td>
<td>1.8</td>
<td>13.5</td>
<td>4726</td>
<td>4517</td>
<td>4622</td>
</tr>
<tr>
<td>Means</td>
<td></td>
<td>1.8</td>
<td>10.9</td>
<td>3881</td>
<td>5310</td>
<td>4370</td>
</tr>
<tr>
<td>MSD</td>
<td></td>
<td>1.4</td>
<td>3.6</td>
<td>534</td>
<td>2388</td>
<td>2211</td>
</tr>
</tbody>
</table>

Discussion
The development of forage bermudagrass for the transition zone between sub-tropical and temperate climates in the United States has progressed for the past 80 years. Coastal bermudagrass became a standard cultivar starting in the 1940’s. ‘Tifton 44’ then was released as a more cold-tolerant cultivar, and for more than half a century was the cultivar recommended for the transition zone. More recently, a number of cultivars were developed at Oklahoma State University that had greater freeze tolerance. However, all of these cultivars were derived from C. dactylon parents which did not confer improvements in forage quality. For quality improvements, C. nlemfuënsis or selected C. dactylon accessions need to be used to increase digestibility. The PI 290660 is a candidate for use as a parent based on field evaluation in the mountains of North Georgia. More accessions need to be tested and used for further advancement. Climate change may make a larger area of the United States more conducive to growing forage bermudagrass and combined with greater freeze tolerant cultivars, more cattlemen and hay producers will reap the benefits.
Acknowledgements
We would like to acknowledge Dr. Yanqi Wu for information from Oklahoma State University and Mr. Freddie Cheek for the work performed at Blairsville, GA.

References


Breeding perennial warm-season grasses for the subtropical belt in South America

Acuña, C.A.¹

¹Instituto de Botánica del Nordeste, CONICET, Facultad de Ciencias Agrarias, UNNE, Corrientes, Argentina.

Key words: polyploidy; apomixis; forage breeding

Abstract
Perennial warm-season grasses share several agronomic characteristics, such as marked seasonal growth, cold susceptibility and photoperiod sensitivity. Breeding efforts in South America have been focused on attempting to improved cool-season growth, cold tolerance and also adaptation to the alternation of flooding and drought periods. Warm-season grasses also have in common that most of them are polyploid and some have very low fertility. Apomixis is also a common trait among these species. For polyploid species with limited seed yield, which commonly have stolons or rhizomes, F₁ hybrids are created and released as cultivars. Acroceras macrum and Hemarthria altissima will be used as examples. For polyploid species without seed fertility issues, such as Setaria sphacelata, recurrent phenotypic selection (RPS) is used to generate improved populations adapted to these transition zones. For polyploid and apomitic species, such as Paspalum spp. and Brachiara spp., several breeding approaches are now available. The generation of F₁ apomictic hybrids is currently used. It has been recently observed that the efficiency of this breeding method can be improved if the genetic distance among parents is considered. There is also new information indicating the great potential of using apomixis-linked molecular markers for the early identification of apomictic hybrids. Population-breeding approaches, such as RPS and selection based on combining ability, can also be used to assess the generation of superior apomictic hybrids. Finally, the challenge of breeding perennial warm-season grasses for the sub tropics mainly relates to improving adaptation to extreme conditions (cold winters and warm summers and alternation of flooding and drought), developing specific breeding techniques for polyploid or apomitic species.

Introduction
Subtropical South America (the land area located between 27 and 31° latitude) represents a transition zone between temperate and tropical regions where warm summers, cool winters, and high photoperiod variation area typical. The amount of precipitation is also highly variable across the region, and drought and flood conditions are also common. Soils usually have low fertility, and acidity or salinity issues are also commonly found. Forage breeders must consider all these characteristics to develop adapted cultivars, particularly perennial forages that are expected to produce across several years.

Perennial warm-season grasses are the most common type of cultivated forages in Subtropical South America, and the genera Brachiaria, Panicum, Chloris, Cynodon, and Paspalum predominate. Polyploidy, variable modes of reproduction, and reduced seed yield are common characteristics in this group of forages (Vogel and Burson 2004). In some species, seed fertility issues limit the possibility of seed reproduction, and vegetative propagation is used. Several species of Cynodon, Acroceras macrum, Hemarthria altissima, and some species of Paspalum and Brachiaria, which usually have rhizomes or stolons are vegetatively propagated. Ecotypes or F₁ hybrids are evaluated in the target environment and superior genotypes are released as cultivars. This type of propagation has become popular in waterlogged soils or areas with periodic floodings in northern Argentina (Ferrari Usandizaga et al., 2015).

Some polyploid species with a more regular meiosis are cross-pollinated and set a moderate amount of seed, which make seed propagation at large scale possible (Vogel and Burson 2004). Chloris gayana, Panicum coloratum, and Setaria sphacelata are good examples of cultivated pastures used in in these transitional climate zones since they tolerate low temperatures during the winter and can be cultivated at higher latitudes in comparison with other warm-season
perennial grasses. Recurrent phenotypic selection is regularly used to breed this group of species.

Apomixis, asexual reproduction through seed, is very common in Brachiaria, Panicum, Cenchrus and Paspalum. This type of reproduction offers the unique opportunity of developing seed propagated F₁ hybrids (Hanna and Bashaw 1987). The large variability present in apomorphic species (Brugnoli et al., 2014) allow breeding for the limiting aspects typical of subtropical environments, such as cold tolerance and cool-season growth (Acuña et al., 2019). However, specific breeding technics need to be used for breeding apomictic species.

The purpose of this paper is to describe the general aspects related to breeding warm-season perennial forages in subtropical South America, and provide examples of breeding activities directly related to the adaptation of new cultivars to these transitional climate zones.

Results

Breeding polyploid species with reduced seed fertility

Acroceras macrum was introduced in Argentina from South Africa about 30 years ago, and has been cultivated as a vegetatively-propagated forage since then. It is usually planted in waterlogged soils between 28 to 31º latitude. The introduced germplasm was variable and two ploidy levels were present (4x=36 and 6x=54) (Ferrari Usandizaga et al., 2015). The species is sexual and cross-pollinated due to self-incompatibility (Ferrari Usandizaga et al., 2020). New hybrids were generated by controlled crosses, and heterosis was observed for cold tolerance and drought tolerance. A few selected hybrids are being evaluated in different locations in Northeastern Argentina aiming to release a new tetraploid cultivar in the near future. A cross-pollinated population has also been created with the purpose of developing a seed-propagated cultivar after a few cycles of selection.

The genus Paspalum L. has several species that grow naturally in swampy areas within the subtropics. Examples of these species are: Paspalum modestum, P. repens, P. palustre, and P. oteroi (Novo et al., 2017) All of them are prostrate growing species that can be vegetatively propagated. An on-farm experiment is underway in order to determine the adaptation of these species to a cultivated environment with seasonal floods. The challenge is to identify germplasm that can tolerate alternating periods of drought and flooding.

About 20 years ago several cultivars of Hemarthrya altissima were introduced in northern Argentina and southern Brazil. The limited adoption of these cultivars was attributed to the lack of seed and the need for vegetative propagation. However, the need to incorporate cultivated pastures in waterlogged soils has renewed the interest for this species. The two better adapted cultivars were Bigalta and Floralta. Two new cultivars were recently developed by the University of Florida named Kenhy and Gibtuck by crossing Bigalta and Floralta (Quesenberry et al., 2018). Since the new cultivars combined the grazing tolerance of Floralta with the high digestibility of Bigalta, they were introduced in Argentina in 2019 as part of an agreement between National University of the North East (UNNE) and University of Florida (UF). They are now being propagated and evaluated in three locations for seasonal forage yield and ground cover.

Breeding polyploid species without limiting seed fertility

Several cultivars of Setaria sphacelata originally developed in Australia have been introduced in Subtropical South America, including Narok, Kazungula, Splenda, and Solander. Improved populations have been recently developed for S. sphacelata in northern Argentina by INTA (National Agricultural Technology Institute, Mercedes Experimental Station) and northern Uruguay by INIA (National Institute of Agricultural Research, Tacuarembó) with the objective of releasing cultivars specifically adapted to the local environmental conditions. These breeding programs have used as the original germplasm the cultivars introduced from Australia, and the main breeding objectives were related to increasing cold tolerance, winter regrowth and seed yield. Recurrent phenotypic selection, and recurrent selection based on combining ability is being used in the program located in Argentina (McLean 2018).

Similar to S. sphacelata, a few cultivars of Panicum coloratum were brought to South America several decades ago. The species is well adapted to heavy soils in the transition between the subtropics and the temperate region of Argentina. A breeding program was established in central Argentina by INTA (Rafaela Experimental Station, 31º11’S, 61º29’W), with the main breeding objectives of developing cultivars with higher seed yield and tolerance to salinity. A cultivar named Kapivera has been developed using recurrent phenotypic selection and released in 2018 and is already in the market (Giordano et al., 2019).
Chloris gayana is also a cross-pollinated species native to Africa as *S. sphacelata* and *P. coloratum*. The species is well known because of its tolerance to drought and salinity. Since salinity is a major limitation in north central Argentina (the Chaco Region), a breeding program was developed by INTA, and diploid and tetraploid cultivars resulted (Ribotta et al., 2020). Diploid cultivars are better adapted to greater latitude in comparison to tetraploid ones. *C. gayana* and *P. coloratum* have great potential for advancing into high latitudes, today temperate zones, as a consequence of global warming.

**Breeding apomictic species**

The main breeding programs for *Brachiaria* and *Panicum maximum* are located in the tropical area of South America, i.e. Colombia (CIAT, Cali) and Brazil (EMBRAPA, Campo Grande), so most developed cultivars are cold sensitive, and not well adapted to the subtropics. However, *Brachiaria brizantha* and *Panicum maximum* are the most important perennial warm-season grasses in the South American seed market (Jank et al., 2014), and cultivars as *B. brizantha* cv. Marandú and *P. maximum* cv. Gatton are among the most commonly sown in the belt between 27 and 28 ° South latitude. Expansion of the cultivation area of these species will be related to the establishment of new breeding programs or evaluation sites (for early evaluations) within higher latitudes (between 29 and 31 ° South).

Apomixis predominates among the more than 300 species of *Paspalum* (Quarin et al., 1992). There are several forage species native to southern Brazil, Northern Argentina, and Uruguay (Acuña et al., 2019). Cultivars have been developed for *P. notatum*, *P. atratum*, *P. guenoarum*, *P. nicorae*, *P. dilatatum* and *P. lenticulare*. The cultivated species better adapted to the subtropics are *P. dilatatum*, *P. notatum* and *P. guenoarum*. Efforts have been made by UNNE (Corrientes, Argentina), University of Buenos Aires (Buenos Aires, Argentina), Federal University of Rio Grande do Sul (Porto Alegre, Brazil) and INIA (Tacuarembó, Uruguay) to improve these species. Several cultivars resulted from these programs, such as *P. notatum* cv. Boyero UNNE, *P. notatum* cv. INIA Sepé, and *P. dilatatum* cv. Relincho UBA.

The technique used to develop most available apomictic cultivars is based on selection among germplasm collections. Examples are *Brachiaria decumbens* cv. Basilisk, *P. maximum* cv. Mombasa, and *P. dilatatum* cv. Relincho. Hybrids generated by crossing induced sexual and apomictic tetraploid plants have been also released as cultivars, such as *Brachiaria* spp. cv. Mulato II, *Panicum maximum* cv. BRS Tamani and *P. notatum* cv. Boyero UNNE. Novel approaches have been developed with the aim to accumulate mainly non-additive genetic effects within synthetic sexual tetraploid populations, which are crossed in each cycle to apomictic male parents to generate improved apomictic hybrids (Miles et al., 2007; Marçon et al., 2020). These novel techniques combine classical and molecular methods as it is described in Figure 1.

**Conclusions**

Several forage breeding programs are active in South America with the objective of developing cultivars adapted to the transition zone between the tropical and temperate regions. Vegetatively propagated hybrids are mainly developed for areas with waterlogged soils. *P. coloratum*, *C. gayana*, *P. notatum*, and *P. dilatatum* are among the seed propagated species with greater potential to advance into highest latitudes within the subtropics or even into the temperate regions. Cold tolerance and cool-season growth are the most limiting traits, however drought and salinity are also major limitations mainly in semiarid regions. Variations of recurrent phenotypic selection are preferentially used for breeding cross-pollinated species. Although ecotypic selection and direct generation of apomictic hybrids are the commonly used techniques for improving apomictic species, new population based methods are being developed and used.

**Acknowledgements**

Support from the National University of the Northeast, the National Scientific and Technical Research Council, the National Agricultural Technology Institute, and the National Agency of Scientific and Technological Promotion are gratefully acknowledged.
References


Figure 1: Theoretical scheme of recurrent phenotypic selection based on a combination of classical and molecular techniques for forage tetraploid *Paspalum notatum*. The molecular markers (MM) use scenarios are indicated at each phase of the process. An image of an experimental/seed production plot of an improved apomictic hybrid cultivar of *Paspalum notatum* (cv. Boyero UNNE) is shown at top right (extracted from Ortiz et al., 2020. Genes, 11:1-27)
Warm-season legumes – Challenges and constraints to adapting warm-season legumes to transition zone climates with examples from *Arachis*

Assis, GML¹; Dubeux Jr., JCB ²

¹Brazilian Agricultural Research Corporation, Rio Branco, AC, Brazil; ²University of Florida, North Florida Research and Education Center, Marianna, FL, United States of America.

Key words: *Arachis glabrata*; *Arachis pintoi*; forage breeding; forage legumes; mixed pastures

Abstract
Grass pastures in monoculture are predominant in transition zone climates, where warm-season perennial grasses are usually cultivated. Mixed grass-legume pastures worldwide have advantages over pure stands, including pasture longevity, N input from biological fixation, efficient nutrient cycling, and greater animal production. The genus *Arachis* encompasses important and successful warm-season forage legume species cultivated in mixed pastures or pure stands. *Arachis pintoi* and *Arachis glabrata* are potential tropical forage species used in transition zone climates. Mixed pastures with these legumes are resilient systems, able to withstand short-term perturbations, like pests, diseases, drought, or flooding. However, the wide adoption of *A. glabrata* is constrained by its high cost and slow establishment period. In addition, this species has a low potential to produce seeds, and rhizomes are required for propagation. Although great seed production is verified in some *A. pintoi* genotypes, vegetative propagation is also most often used since seeds are produced underground, and large-scale commercial seed production depends on developing an efficient seed harvester and developing new cultivars with the persistent link between seed and peg. In tropical regions, *A. pintoi* spreads faster than *A. glabrata*, and the genetic variability for lateral expansion and ground cover in mixed stands must be better understood in humid subtropical climates. The evaluation of *Arachis* wild germplasm has already shown genetic variability for traits of interest for use in mixed pastures. Studies have also shown that there is genotype x environment interaction considering tropical and subtropical climates. The greatest chances of success in obtaining more adapted, productive, and faster establishing *Arachis* cultivars for transition zone climates seem to be no longer in identifying superior wild accessions but in the hybridization and selection through specific breeding programs.

Introduction
Regions between tropical and temperate climates (latitudes from 20° to 35° North and South) usually present hot summers and winters with medium temperatures but with frequent frosts. Part of these transition climate zones is the humid subtropical climate, also characterized by the uniform distribution of rainfall throughout the year (Britannica 2018). In summer, the average temperature is 27°C (reaching a daily maximum of 30 to 38°C), while in winter, the temperature usually fluctuates between 5 and 12°C in the coldest months. There are records of temperatures in these regions below 0°C on some winter days.

The cultivation of perennial forage species in these regions is a challenge. Tropical species show full development and growth in the hottest months of the year but are no longer productive with winter’s arrival and the occurrence of frosts. On the other hand, typically temperate species do not develop or even survive high summer temperatures.

Among tropical forage legumes, species of the genus *Arachis* L. are quite promising for cultivation in transition zone climates (French *et al.*, 1993). Two species are used prominently in different countries: *Arachis glabrata* Benth. and *Arachis pintoi* Krapov. & W.C. Greg., known as perennial peanut and forage peanut, respectively.

This work aims to present the main limitations and challenges for adaptation and increased adoption of these species in transition zone climates and the characteristics and current uses of *A. glabrata* and *A. pintoi* in agricultural systems.

Characteristics and use
*A. glabrata* and *A. pintoi* are herbaceous forage legumes with prostrate growth habits, reaching 20...
to 40 cm in height. Both are palatable, have no antinutritional factors, as commonly seen in other legume species and present high nutritional value, with elevated levels of protein and digestibility, including their tender stems, being similar to alfalfa (Terril et al., 1996).

However, they have important genetic and morpho-agronomic differences (Krapovickas and Gregory 2007). *A. glabrata* is a tetraploid species (2n=4x=40) from the Rhizomatosae section. It is characterized by the presence of rhizomes, which guarantee its survival even in adverse conditions, such as frost and drought. On the other hand, seed production, if present, is scarce. *A. pintoi*, in turn, is diploid (2n=2x=20) and belongs to the Caulorrhizae section. Instead of rhizomes, it presents stolons with a high number of growth points, capable of rooting in contact with moist soil. A wide range of seed productivity has already been identified in forage peanut genotypes, from the absence to the production of more than 4 tons of seeds per hectare in 18 to 21 months after planting.

Research shows the benefits of forage Arachis spp. use in tropical and subtropical animal production systems due to the biological nitrogen fixation (BNF). The amount of nitrogen fixed in *A. glabrata* and *A. pintoi* is genotype-dependent (Miranda et al., 2003; Dubeux et al., 2017) and is directly influenced by its productivity and persistence. BNF by forage legumes is estimated between 110 to 227 kg of nitrogen per hectare annually (Herridge et al., 2008).

Rhizomatous and stoloniferous legumes as perennial and forage peanuts do not necessarily depend on natural reseeding, as they multiply vegetatively, which guarantees the permanence of their population in the pasture. Both are quite palatable and have excellent tolerance to grazing; that is, they can resist defoliation and trampling, as they keep their growth points protected and have physiological mechanisms that allow regrowth (Andrade et al., 2015). Therefore, mixed pastures with these legumes have been shown to be resilient systems and withstand short-term perturbations, like pests, diseases, drought, or flooding. Such resilience has also been observed for frosts and low temperatures, eventually under 0°C. Despite the loss of aerial biomass, these species can regrow vigorously as the temperature and precipitation increase.

The forage use of these species in tropical and subtropical regions is consolidated in countries like Brazil, the United States, Southeast Asia, Australia, and Argentina. In the United States, *A. glabrata* is widely used to produce hay in Florida, Georgia, and Alabama, estimated in more than 10,000 hectares in 2008 (NRCS 2008). In Brazil, more than 80,000 hectares of mixed pastures are cultivated in tropical regions (EMBRAPA 2018). In the south of this country (from 22 °S to 32°S), it is also found in consortium with grasses and as a cover crop in perennial plantations.

**Challenges and constraints**

Both forage legumes develop better in regions with temperatures around 25 °C, but they can survive in average temperatures of 18 °C, with frost occurrences. The natural distribution of *A. glabrata* is wider (13ºS to 28ºS) than *A. pintoi* (13ºS to 17ºS), giving it a better natural adaptation in subtropical climates.

**Arachis glabrata**

The evaluation of *A. glabrata* genotypes initiated in the 1960s in transition zone climates resulted in at least eleven cultivars released mainly in the United States. The productivity of those cultivars selected for animal systems exceeds 10 Mg ha-1 year-1 (Quesenberry et al., 2010; Dubeux et al., 2017). Despite the advantages of its use, greater adoption has constraints related, mainly: (i) to use rhizomes for the establishment of pasture or hay production areas and (ii) to the slow establishment of cultivars. The nursery for removing rhizomes to establish new areas should remain intact for 12 months, and the optimum rate for planting is estimated at 2.5 Mg ha-1 (Cathey 2010). Despite mechanized planting, the operationalization of the entire process is laborious and expensive.

It is important to highlight that the released cultivars result from the evaluation and selection of the best genotypes, whose tools related to artificial hybridization to generate variability were not used. Among the accessions evaluated, none has been identified as a good seed producer, a limitation of *A. glabrata*. The scarce or null production of seeds brings difficulties for cultivation areas and makes it difficult to implement genetic improvement programs based on intraspecific hybridization to generate genetic variability. However, there is the possibility of obtaining F1 hybrids that could be artificially generated and evaluated, looking for high heterosis, selecting the most productive and vigorous ones. Florigraze is probably a natural hybrid that originated from cultivated genotypes. Alternatives can also be related to the evaluation of accessions not yet tested in regions of transition zone climates or even the collection of new genotypes in areas of natural occurrence to increase the genetic base. A long-term challenge would be to invest in interspecific hybridization programs. Intersectional crosses...
between *A. glabrata* and other species of the genus *Arachis* have already been shown to be viable, with fertile hybrids (Mallikarjuna 2002). However, the complexity of the process imposes new difficulties to breeders because when generating such hybrids, important characteristics that bring advantages to the cultivation of *A. glabrata* in transition zone climates are altered, such as the loss of rhizomes in F1 hybrids of *A. glabrata* and *Arachis hypogaea* L. (Mallikarjuna and Sastrī, 2002).

### Arachis pintoi

Unlike *A. glabrata*, most of the released cultivars of *A. pintoi* were evaluated and selected for tropical regions. One of the exceptions is the cultivar Alqueire-1, selected for the Brazilian humid subtropic, but which has shown a high occurrence of viruses. Information about the agronomic performance and persistence of *A. pintoi* in subtropical regions is relatively scarce. Productivity observed in 24 *A. pintoi* accessions, without previous selection, evaluated at latitude 29ºN in the state of Florida (USA) ranged from zero to 9.1 Mg ha-1, with an average of 4.4 Mg ha-1 (Carvalho and Quesenberry 2012). In this study, seed production proved to be viable, with values above 1 Mg ha-1.

In tropical regions, dry matter accumulation of released cultivars is greater, varying from 7 to 20 Mg ha-1 yr-1 in pure stands (PASTO CERTO 2019). However, it should be noted that the evaluation trials and selection of forage peanut genotypes in tropical regions have been carried out continuously for more than 20 years, with the structuring of genetic improvement programs, thus creating the possibility of greater advances in agronomic response within the species.

Leaf loss and death of *A. pintoi* stolons are observed during the winter in subtropical regions; however, the plants can survive and regrow vigorously, with a total recovery of their aerial biomass as the temperature increases. Carvalho and Quesenberry (2012) highlight that “*A. pintoi* can tolerate winters where freezing and frosting are normal occurrences”. Therefore, developing forage peanut cultivars with great seed production and better adapted to the subtropical climate is a very promising strategy.

According to the Forage Peanut Breeding Program, the Brazilian Agricultural Research Corporation (Embrapa) started the selection of *A. pintoi* genotypes at latitude 31ºS in 2012, according to the Forage Peanut Breeding Program (Assis and Valentim 2013), which aims to develop cultivars of forage peanut for different edaphoclimatic regions of the country. The selected genotypes were artificially crossed to obtain F1 hybrids directed to the generation advance stage to increase homozygosity and obtain lines, which will be evaluated later in such environments. At latitude 31ºS in the state of Rio Grande do Sul (Brazil), wild accessions presented forage accumulation greater than the cultivars Amarillo, Belmonte, and BRS Mandobi and, even, greater than cv. Alqueire-1, selected for the subtropical climate (Naylor Bastian Perez, personal communication). However, an expansion of agronomic performance of wild accessions from the Germplasm Bank in regions of transition zone climates is still necessary.

The slow establishment observed in *A. glabrata* also occurs in *A. pintoi*, especially when propagated through stolons. However, the great advantage of the latter is the possibility of developing cultivars with great seed productivity and, thus, using greater sowing rates for faster coverage of the area. This strategy, however, comes up against another limitation, which is the difficulty in harvesting the seeds. The fruit is detached from the mother plant when ripe in wild species of the genus *Arachis* and, usually, the harvest is 7-cm deep by digging the soil, which must be sieved to separate the seeds. Therefore, another major challenge for reducing the cost of production and increasing the seed supply is developing an efficient mechanized process for harvesting *A. pintoi* seeds (Sampaio et al., 2019).

Furthermore, successful interspecific crosses to obtain hybrids that keep the pegs rigid, even after the pods have matured, is a great challenge for breeders. It would be necessary to get hybrids between *A. pintoi* and *A. hypogaea*. Investing in the chromosomal duplication of *A. pintoi* with colchicine first and then fertilizing the plant with the tetraploid species is a strategy (Holbrook et al., 2016).

### Conclusions

Wild forage legume accessions from germplasm banks evaluated in transition zone climates have genetic variability and forage potential for use in livestock systems, including the possibility of releasing cultivars propagated by seeds. Making forage peanut seeds available on the market is a major challenge and depends on the performance of a multidisciplinary team to be successful. The demand for forage legume seeds adapted to the subtropical climate to produce hay and to establish stable and persistent mixed pastures with different grasses is growing strongly, especially for the benefits from BNF. The greatest chances of success in obtaining more adapted, productive, and faster establishing *Arachis* cultivars for transition zone climates seem to be no longer in identifying superior wild accessions but in the hybridization and selection through specific breeding programs.
References


In P.C. Kerridge and B. Hardy (ed.) *Biology and agronomy of forage Arachis*. CIAT, Cali, Colomb


In P.C. Kerridge and B. Hardy (ed.) *Biology and agronomy of forage Arachis*. CIAT, Cali, Colomb


THEME: 2 FORAGE PRODUCTION AND UTILIZATION

Topic: Recent Advances in Urochloa grass Grass Research in Kenya
Growth and yield evaluation of urochloa grass cultivars in sub-humid region of Kenya

Kifuko-Koech M. N.1, Ndung’u-Magiroi, K.W.1, Mutoko, M.C1., Kamidi, M1., and Njarui, D.M.G2.

1Kenya Agricultural and Livestock Research Organization (KALRO) – Kitale, P.O. Box 450, Kitale, Kenya.
2KALRO- Katumani, P.O. Box 340, Machakos, Kenya.

*Correspondance: Tel: +254 722373530, E-mail: kifukom@yahoo.com.

Key words: Urochloa cultivars; dry matter yield; nutritive quality, height; plot cover; spread

Abstract
Livestock production in sub-humid region of Kenya is constrained by inadequate and low quality pasture. A study was conducted to evaluate growth and productivity of eight improved Urochloa grass cultivars in lower midlands, upper midlands and lower highlands agro-ecological zones (AEZ) in Eldoret, Kitale and Alupe respectively, western Kenya. The grass cultivars were; Urochloa brizantha cv. Marandu, Xaraes, Piata, and MG-4, U. decumbens, cv. Basilisk, U. humidicola cv. Humidicola and Llanero and Urochloa hybrid cv. Mulato II. Rhodes grass (Chloris gayana) and Napier grass (Pennisetum purpureum cv. Kakamega 1) were included as controls. At establishment stage, growth parameters (height, cover and spread) and dry matter yield (DMY) were monitored at 14 weeks after seedling emergence (WAE) and standardization cut conducted to stimulate uniform plant growth. Thereafter (production stage), the plants were repeatedly harvested for DMY determination at 6, 8 and 12 weeks intervals. The growth parameters and DMY varied significantly (P<0.05) among the cultivars in all the AEZ in all the measurement dates. Napier grass recorded the highest mean height (60 to 120 cm) at the end of establishment period while among Urochloa cultivars, MG-4, Basilisk and Xaraes recorded the highest mean height and plot cover across all AEZs. All Urochloa cultivars gave significantly (P<0.05) lower DMY than Napier grass in Kitale and Alupe while Basilisk and Xaraes recorded similar DMY to Napier grass in Eldoret. In Eldoret, Xaraes recorded the highest DMY (2.54 t ha⁻¹) while in Kitale and Alupe the highest DMY was recorded in MG-4 (3.7 t ha⁻¹) and Basilisk (4.72 t ha⁻¹), respectively. Increasing cutting interval increased DMY but reduced nutritive value of Urochloa cultivars in Kitale. Basilisk, MG-4, Xaraes and Piata showed potential to establish and grow well across AEZs and to maximize production and nutritive value cutting at 8 weeks interval is recommended.

Introduction
Dairy farming is an important enterprise for the livelihoods of many households in western Kenya, as a source of income and employment. Unfortunately, many small-scale farms in this region depend on natural pastures, which are inadequate and of poor quality and this affect dairy production. One approach to achieve increased livestock production is through introduction of high quality forages, which are nutritious with wide ecological adaptation such as Urochloa grass (Maass et al., 2015). Improved Urochloa grass produce high biomass, enhance soil fertility, reduce greenhouse gas emission (Peters et al., 2012), contribute to carbon sequestration (Dijkeng et al., 2014) and are tolerant to most pests and diseases. There has been previous effort to include improved Urochloa grass cultivars in eastern region of Kenya (Nguku et al., 2016) but there is little information on adaptability and management of these cultivars in sub-humid region of western Kenya. The objective of this study was therefore to assess adaptability, herbage accumulation and nutritive value of Urochloa grass cultivars under different regrowth intervals in humid region of western Kenya.

Materials and Methods
The study was conducted at Eldoret (0° 29’ 19’’ N and 35° 20’ 26´´E), Kitale (1° 0’ 6.6’’N and 34°
59° 10' E) and Alupe (1° 28' N) located in lower midlands (LH3), upper midlands (UM3) and lower highlands (LM3) agro-ecological zones (AEZ) of western Kenya, respectively. Soil in Alupe and Eldoret are Rhodic Ferralsols with moderate acidity and low nutrient content while major soils in Kitale are Acrisols/Luvisols with varying level of compaction due to high clay content (Muya et al., 2017). Rainfall in Alupe is bimodal while Kitale and Eldoret have unimodal rainfall pattern. Alupe had higher amount of annual precipitation (1366-1781 mm), followed by Kitale (1275-1341 mm) and Eldoret (752-898 mm) during study period (2014-2015).

Seven Urochloa grass cultivars; Urochloa decumbens cv. Basilisk, B. humidicola cvs. Llanero and Humidicola, B. brizantha cvs. Marandu, MG-4, Piatà, Xaraes and B. hybrid cv. Mulato II were compared with Rhodes grass (Chloris gayana) and Napier grass (Megathyrsus maximus formerly Pennisetum purpureum cv. Kakamega 1). The treatments were arranged in a randomized complete block design with three replications in plot sizes of 4 m x 5 m. At planting, triple super phosphate (TSP, 46 % P$_2$O$_5$) fertilizer was applied in the planting furrows at a rate of 40 kg P ha$^{-1}$. The seeds were manually drilled at an inter row spacing of 0.5 m, at seed rate of 5 kg ha$^{-1}$. Three (3) root splits of Napier grass were planted in holes 15 cm deep at a spacing of 1 m within and between rows. Data was collected during the establishment and production phase, which lasted for three years (2014-2016). The establishment period was considered to be up to 14 weeks after seedling emergency (WAE) while subsequent period that included (three seasons) two dry and one wet seasons were regarded as production phase. Data collection included growth parameters (height, plot cover, spread) and dry matter yield (DMY) taken at 14 WAE from 4 m$^2$ net plot. At the start of production phase (14 WAE), a standardization cut was conducted in all plots to stimulate uniform growth and plots were split into three equal portions and allocated three cutting intervals i.e. 6, 8 and 12 weeks at random which were conducted for two dry and one wet seasons. Due to high cost of analysis, plant samples from Kitale site (dry season) were selected for chemical composition analysis. Crude protein, neutral detergent fibre (NDF) and in-vitro matter digestibility (IVDMD) were determined using procedure outlined in AOAC (2000), Van Soest et al., (1991), Goering and Van Soest (1970). The generated data was subjected to analysis of variance (ANOVA) using a general linear model (SAS 2001) and means separated by least significance difference (LSD) and standard error of difference (SED).

Results

Adaptability and growth characteristics at establishment phase

Table 1 shows growth characteristics and DMY during establishment period. Most grass cultivars established well in all sites except Humidicola, Llanero, Mulato II and Rhodes in Alupe and Kitale. At 14 WAE, Napier grass was the tallest (60 - 120 cm) in all sites while all Urochloa cultivars were significantly shorter than Rhodes in Alupe. Among Urochloa cultivars, MG-4, Marandu and Basilisk were the tallest in Kitale, Eldoret and Alupe, respectively while Humidicola, Llanero and Mulato II were the shortest across AEZs. In all sites, Napier grass significantly (P < 0.05) spread more (23 - 80 cm) than all the Urochloa grass cultivars (6.3 - 51.3 cm) while among Urochloa cultivars, Basilisk had the highest spread (25 - 51.3 cm). Mulato II and Marandu had the lowest spread and were comparable with Rhodes grass. Napier grass attained the highest plot cover while among Urochloa cultivars, Xaraes, MG-4 and Basilisk recorded the highest plot cover. All grass cultivars had higher DMY in Alupe compared to other AEZs and the most productive Urochloa cultivars were Xaraes (2.54 t ha$^{-1}$), MG-4 (3.7 t ha$^{-1}$) and Basilisk (4.7 t ha$^{-1}$) in Eldoret, Kitale and Alupe, respectively. Rhodes grass, Humidicola and Mulato II had the lowest DMY.
Seasonal dry matter yield at production phase

During production stage, dry matter yield was assessed for three seasons that included two dry (dry 1 and 2) and one wet seasons (wet 1). Seasonal effects showed that all the *Urochloa* grass cultivars persisted during the dry season while Rhodes grass succumbed to drought in Alupe. *Urochloa* cultivars were more productive in Kitale than in the other sites. During the wet season, the most productive cultivars were Basilisk, Llanero and Xaraes in Eldoret, Kitale and Alupe, respectively. At the end of production phase (dry 2), the most productive cultivars were MG-4, Mulato II and Xaraes in Eldoret, Kitale and Alupe, respectively.

**Table 2**: Seasonal dry matter yield (t/ha) in Kitale, Eldoret and Kitale sites

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Kitale Dry 1</th>
<th>Wet 1</th>
<th>Dry 2</th>
<th>Eldoret Dry 1</th>
<th>Wet 1</th>
<th>Dry 2</th>
<th>Alupe Dry 1</th>
<th>Wet 1</th>
<th>Dry 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilisk</td>
<td>2.85</td>
<td>11.67</td>
<td>10.53</td>
<td>4.13</td>
<td>14.30</td>
<td>8.19</td>
<td>2.46</td>
<td>3.84</td>
<td>2.63</td>
</tr>
<tr>
<td>MG4</td>
<td>2.31</td>
<td>12.28</td>
<td>8.01</td>
<td>3.67</td>
<td>12.68</td>
<td>10.13</td>
<td>2.31</td>
<td>2.84</td>
<td>2.22</td>
</tr>
<tr>
<td>Marandu</td>
<td>2.64</td>
<td>11.86</td>
<td>6.98</td>
<td>2.74</td>
<td>10.34</td>
<td>6.09</td>
<td>2.27</td>
<td>3.16</td>
<td>1.73</td>
</tr>
<tr>
<td>Piata</td>
<td>2.15</td>
<td>13.16</td>
<td>7.10</td>
<td>2.82</td>
<td>12.46</td>
<td>6.58</td>
<td>2.55</td>
<td>3.35</td>
<td>2.38</td>
</tr>
<tr>
<td>Xaraes</td>
<td>1.73</td>
<td>12.65</td>
<td>8.45</td>
<td>3.66</td>
<td>11.45</td>
<td>6.82</td>
<td>3.16</td>
<td>5.21</td>
<td>3.90</td>
</tr>
<tr>
<td>Mulato II</td>
<td>1.58</td>
<td>11.90</td>
<td>11.00</td>
<td>1.83</td>
<td>8.81</td>
<td>5.26</td>
<td>2.02</td>
<td>2.64</td>
<td>1.24</td>
</tr>
<tr>
<td>Llanero</td>
<td>-</td>
<td>14.25</td>
<td>6.30</td>
<td>-</td>
<td>-</td>
<td>3.85</td>
<td>2.66</td>
<td>3.73</td>
<td></td>
</tr>
<tr>
<td>Humidicola</td>
<td>-</td>
<td>2.36</td>
<td>8.88</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.54</td>
</tr>
<tr>
<td>Rhodes grass</td>
<td>-</td>
<td>10.70</td>
<td>5.54</td>
<td>7.60</td>
<td>5.36</td>
<td>1.06</td>
<td>0.68</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.21</td>
<td>11.20</td>
<td>8.09</td>
<td>3.14</td>
<td>11.09</td>
<td>6.92</td>
<td>2.46</td>
<td>3.05</td>
<td>2.42</td>
</tr>
<tr>
<td>LSD (P &lt; 0.05)</td>
<td>2.21</td>
<td>1.82</td>
<td>3.68</td>
<td>0.68</td>
<td>2.43</td>
<td>1.05</td>
<td>0.81</td>
<td>1.12</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Effect of cutting intervals on dry matter yield and nutritive quality at production phase
Effect of cutting intervals on DMY showed that during the dry season, *Urochloa* cultivars were more productive when cut at shorter intervals (6 or 8 weeks) while prolonging the cutting interval to 12 weeks gave higher DMY during wet season across AEZs. The level of most of the nutritive parameters decreased significantly (P < 0.05) with increasing cutting intervals and cutting at either 6 or 8 weeks interval resulted to higher crude protein and *in-vitro* dry matter digestibility (Table 3). All the *Urochloa* cultivars had lower fibres than Rhodes grass and consequently were more digestible.

**Table 3: Effect of cutting frequencies on herbage nutritive value in Kitale during second dry season**

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Crude protein (%)</th>
<th>Mean</th>
<th>In-vitro dry matter digestibility (%)</th>
<th>Mean</th>
<th>Neutral Detergent Fibre (%)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>Mean</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Basilisk</td>
<td>15.9</td>
<td>15.7</td>
<td>10.4</td>
<td>14.0</td>
<td>67.1</td>
<td>68.8</td>
</tr>
<tr>
<td>MG4</td>
<td>14.8</td>
<td>12.6</td>
<td>8.9</td>
<td>12.1</td>
<td>66.4</td>
<td>67.7</td>
</tr>
<tr>
<td>Marandu</td>
<td>14.9</td>
<td>15.1</td>
<td>11.0</td>
<td>13.7</td>
<td>64.7</td>
<td>67.9</td>
</tr>
<tr>
<td>Mulato II</td>
<td>14.6</td>
<td>17.5</td>
<td>16.7</td>
<td>16.2</td>
<td>59.4</td>
<td>56.8</td>
</tr>
<tr>
<td>Piata</td>
<td>14.0</td>
<td>15.5</td>
<td>10.9</td>
<td>13.5</td>
<td>70.0</td>
<td>68.6</td>
</tr>
<tr>
<td>Xaraes</td>
<td>14.3</td>
<td>14.0</td>
<td>10.4</td>
<td>12.9</td>
<td>63.9</td>
<td>64.1</td>
</tr>
<tr>
<td>Rhodes grass</td>
<td>11.0</td>
<td>14.3</td>
<td>5.6</td>
<td>10.3</td>
<td>61.9</td>
<td>60.6</td>
</tr>
<tr>
<td>Mean</td>
<td>14.21</td>
<td>14.97</td>
<td>10.56</td>
<td>10.3</td>
<td>61.9</td>
<td>64.9</td>
</tr>
</tbody>
</table>

**SED-**standard error of difference

**Discussion and conclusion**

All grass cultivars established well in Alupe and Kitale compared to Eldoret possibly due to differences in time of establishment and rainfall amount. While planting of the grass in Kitale and Alupe was conducted during rainy season, in Eldoret it was conducted a few days to cessation of rains. In Alupe and Kitale most *Urochloa* cultivars showed upright growth characteristics whereas in Eldoret the same cultivars showed a spreading growth habit. Pasture species, which grow fast and tall are more competitive, efficient in utilization of resources, and likely to have higher biomass production (Mnga 2009, Nguku et al., 2016). Among the *Urochloa* cultivars, Basilisk, MG-4 and Xaraes were the tallest and had the largest cover (> 50%) and DMY at the end of establishment and production phases across sites. This is an indication that they can be a good alternative to Rhodes grass and Napier. Basilisk has extensive roots system, aggressive growth habit, dense cover and utilizes nitrogen efficiently (Loch 1997). Xaraes is reported to have greater leaf and stem elongation rates and higher leaf blade, which results to higher biomass production since the stem, is the structural component with higher weight than leaves (Rodrigues et al., 2014). The low yield of Humidicola, Llanero and Mulato II was attributed to the slow establishment and attack of Mulato II by red spider mites, which are the most prevalent pests in *Urochloa* cultivars (Mutisya et al., 2018). The difference in yield due to cutting intervals and seasons was attributed to rainfall distribution and moisture availability. For many grasses, longer regrowth intervals result in greater herbage accumulation when moisture is sufficient and therefore results of this study support conclusion of other authors (Hare et al., 2013). Overall, the CP for all *Urochloa* cultivars was well above 7% and higher than levels recorded in Rhodes, which is considered critical for livestock production. Although DMY increased and decreased with increasing cutting intervals during wet and dry seasons respectively, cutting at 8 weeks resulted to high nutritive quality and beyond this stage, quality was compromised. Among the *Urochloa* cultivars, Basilisk, MG-4, Xaraes and Piata gave higher DMY and nutritive qualities and are a good alternative to Rhodes grass and Napier in the study area.
Acknowledgements
The study was undertaken in collaboration between Kenya Agricultural and Livestock Research Organization (KALRO) and Biosciences eastern and central African - International Livestock Research Institute (BecA-ILRI) Hub, Nairobi and was funded by the Swedish International Development Cooperation Agency (Sida). We are grateful to KALRO - Kitale and University of Eldoret staff for their technical support.

References


Milk yield of dairy cattle fed common Urochloa grass in Kenya

Muinga, R.W.1*, Njunie, M.N.2, Gatheru, M.3 and Njarui, D.M.G.3

1Kenya Agricultural and Livestock Research Organization (KALRO) Headquarters, Nairobi, Kenya
2Kenya Agricultural and Livestock Research Organization - Matuga, Kenya
3Kenya Agricultural and Livestock Research Organization - Katumani, Kenya
*Corresponding author email: rwmuinga83@gmail.com

Abstract

Urochloa grass mainly grown in South America, East Asia and Australia has its origin in East and Central Africa. Its success in South America for animal production triggered interest in Kenya where the main forage species Napier grass was threatened by head smut and stunt diseases. Therefore, a study was carried out at Mtwapa research station in the coastal lowlands of Kenya under controlled condition to compare the lactation performance of dairy cattle fed on Urochloa hybrid cv. Mulato II, U. decumbens cv. Basilisk, U. brizantha cvs. Piata, MG-4 and Xaraes with Napier grass. An on-farm participatory study was conducted in eastern midlands of Kenya where farmers compared their local feeds (varied mixtures of Napier grass, maize stover and natural pastures) with either Piata, Xaraes, MG-4 or Basilisk. Results from the on-station experiment showed no significant differences (P < 0.05) in daily milk yield between dairy cows fed Piata (4.7 kg) and those fed on Napier grass (4.6 kg) while cows fed on either Mulato II or Xaraes produced less (P < 0.05) milk; 4.4 and 3.6 kg respectively. In the farmers’ trial, milk yield increased by 15 - 40% when they fed their cows on Urochloa grasses. The studies concluded that Urochloa grasses had potential to replace or compliment Napier grass in dairy feeding in Kenya towards increased milk production.

Key words: dairy cows, milk yield, lactation performance, feed intake, participatory evaluation, Kenya

Introduction

Natural pastures are the main feed resource mainly under free-grazing system in coastal lowlands (Njarui et al., 2016). Milk production for local and exotic/crossbred cattle is low, ranging from 1.0 to 6.4 kg day−1 respectively (Ramadhan et al., 2008). Napier grass (Pennisetum purpureum Schumach.), has been promoted in Kenya as the basal feed for dairy cattle. The grass grows under a wide range of conditions and is a valuable forage for the cut-and-carry systems. Napier grass contributes about 10% of feed in coastal Kenya, 35 - 45% in northwestern highlands and about 50% in the central highlands (Njarui et al., 2016). Increased milk production has been recorded where lactating dairy cattle were fed Napier grass supplemented with forage legumes (Juma et al., 2006). Despite its wide promotion and positive effect on milk production, it is challenged by the stunting disease and head smut which calls for alternative grasses. Urochloa species are being re-introduced to the region as potential alternatives to Napier grass (Mureithi and Djikeng 2016). Urochloa species are native to eastern and central Africa and are extensively grown as livestock forage in South America and East Asia (FAO 2015). The annual dry matter yield ranges from 8 to 20 t/ha depending on moisture and nutrients (FAO 2015). Urochloa grasses are among the most nutritious forages in the humid tropics. For example, crude protein in B. brizantha ranges from 5 to 16% crude protein and about 58% in vivo organic matter digestibility (Heuzé et al., 2016). The current studies evaluated Urochloa grasses as basal feed for lactating cows under controlled conditions in coastal lowland Kenya and by farmers in mid-altitude eastern region.

Materials and methods

On-station study

The study was carried out at KALRO Mtwapa (3°56′ S, 39°44′ E) in the coastal lowlands at an altitude of 15 m above sea level. The site is characterized by light sandy soils and a mean annual rainfall of 1200 mm. The relative humidity ranges from 65 - 95% and the mean annual temperatures range from 24 to 29°C. Sixteen
lactating Jersey cows with pre-experiment milk yield ranging from 4 to 5 kg/day and weighing 257 ± 38 kg were used in the experiment. The cows were divided into four groups balanced for milk yield and live weight. The cows were housed in individual feeding stalls and allowed a three weeks acclimatization period on the treatment diets. Napier grass (\textit{Pennisetum purpureum}), glicidica (\textit{Gliricidia sepium}) and grass cultivar (\textit{B. hybrid} cv. Mulato II, \textit{B. brizantha} cvs. Piata, Xaraes) were used for the experiment. The grasses were harvested daily and chopped with a motorized chaff cutter while Glicidica leaves and stems of less than 5 mm diameter were harvested and wilted a day before feeding the cows. Four treatments (cvs. Mulato II, Piata, Xaraes and Napier grass cv. Bana) were allocated to the four groups of cows in a completely randomized design. All cows were supplemented with 8 kg fresh glicidica and 3 kg maize bran in two equal amounts daily at milking in all the groups. Each cow was allowed 60 g of a dairy mineral mix and clean cool water was provided \textit{ad libitum}. Data was collected on feed intake and milk yield for 10 weeks. Composite samples of each feed (maize bran, glicidica, grasses) were taken at three stages (onset, mid and end of the trial) for chemical analyses (Crude protein, Neutral detergent fibre, Acid detergent fibre, Acid detergent lignin, Ash, Calcium, Phosphorous and digestibility). Data on weight and chemical composition was analysed and means were separated using the least significant difference (LSD) at P < 0.05 (SAS 2003).

**Results and Discussion**

**On station study**

**Feed composition**

Glicidica had the highest CP (24.4%) and lowest NDF (34.9%) which was significantly (P < 0.05) different from the grasses. Its dry matter and organic matter digestibility were however similar (P > 0.05) to that of Napier grass, Mulato II and Piata and different (P < 0.05) from Xaraes (Table 1). Digestibility is positively affected by CP and negatively by NDF content. Xaraes had the lowest CP and digestibility and the highest NDF but these values were similar (P>0.05) to those recorded for Napier grass, Mulato II and Piata. Similarly, the grasses had similar ADF, ADL, Ca and P. The harvesting stage of the \textit{Urochloa} grasses used in this study was variable. A composite sample of each harvested at three different stages was analyzed (Table 1). The CP and OMD values of the \textit{Urochloa} cultivars in this study were lower than those reported by Nguku (2015) in the medium attitude Machakos. The CP was 6.9, 5.8, 5.6 and 4.9% for Napier grass, Mulato II, Piata and Xaraes which was like values reported in the current study (Table 1).

**Table 1:** Chemical composition and digestibility of the feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>CP</th>
<th>NDF</th>
<th>Ash</th>
<th>DMD</th>
<th>OMD</th>
<th>ADF</th>
<th>ADL</th>
<th>Ca</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize bran</td>
<td>12.6</td>
<td>58.0</td>
<td>8.5</td>
<td>66.8</td>
<td>61.8</td>
<td>21.4</td>
<td>2.6</td>
<td>0.9</td>
<td>0.03</td>
</tr>
<tr>
<td>\textit{Gliricidia sepium}</td>
<td>24.4</td>
<td>34.9</td>
<td>7.7</td>
<td>57.5</td>
<td>51.5</td>
<td>34.4</td>
<td>17.3</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>\textit{P. purpureum} cv. Bana</td>
<td>6.8</td>
<td>67.3</td>
<td>7.9</td>
<td>48.6</td>
<td>43.3</td>
<td>50.1</td>
<td>14.0</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>\textit{U. hybrid} cv. Mulato II</td>
<td>5.5</td>
<td>66.2</td>
<td>6.1</td>
<td>46.6</td>
<td>42.2</td>
<td>50.6</td>
<td>8.9</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>\textit{U. brizantha} cv. Piata</td>
<td>5.3</td>
<td>68.9</td>
<td>5.0</td>
<td>43.2</td>
<td>40.0</td>
<td>52.5</td>
<td>13.6</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>\textit{U. brizantha} cv. Xaraes</td>
<td>5.0</td>
<td>70.7</td>
<td>5.4</td>
<td>35.2</td>
<td>32.9</td>
<td>52.3</td>
<td>9.4</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>LSD (P &lt; 0.05)</td>
<td>3.67</td>
<td>8.10</td>
<td>2.36</td>
<td>16.07</td>
<td>14.28</td>
<td>10.45</td>
<td>9.52</td>
<td>0.08</td>
<td>0.368</td>
</tr>
</tbody>
</table>

LSD Least significant difference
Feed intake and milk yield

The daily basal grass diet DM intake was similar (P > 0.05) for cows fed on Napier grass (5.7 kg) and those fed Piata (5.8 kg) and was different (P < 0.05) from that of cows fed Mulato II (6.3 kg) or Xaraes (6.4 kg). Mean daily milk production for all the cows was low (4.3 kg cow⁻¹), probably due to the late stage of lactation at the start of the experiment. Cows fed Piata (4.7 kg) and Napier grass (4.6 kg) was similar (P > 0.05). However, cows fed on Mulato II (4.4 kg) and Xaraes (3.6 kg) produced less (P<0.05) milk daily compared to those fed on Piata and Napier grass (Table 2).

Table 2: Daily basal grass diet intake (kg DM) and milk yield (kg) per cow

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grass DM intake</th>
<th>Total DOM intake</th>
<th>Milk yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>U. brizantha</em> cv. Piata</td>
<td>5.8</td>
<td>5.3</td>
<td>4.7</td>
</tr>
<tr>
<td><em>P. purpureum</em> cv. Bana</td>
<td>5.7</td>
<td>5.5</td>
<td>4.6</td>
</tr>
<tr>
<td><em>U. hybrid</em> cv. Mulato II</td>
<td>6.3</td>
<td>5.1</td>
<td>4.4</td>
</tr>
<tr>
<td><em>U. brizantha</em> cv. Xaraes</td>
<td>6.4</td>
<td>4.9</td>
<td>3.6</td>
</tr>
<tr>
<td>LSD (P &lt; 0.05)</td>
<td>0.29</td>
<td>-</td>
<td>0.14</td>
</tr>
</tbody>
</table>

LSD, Least significant difference

Total Digestible Organic Matter (DOM) intake = Dry Matter (DM) intake*Digestibility for grass, gliricidia and maize bran

Cows fed on Xaraes had the highest DM intake and the lowest milk yield, while the digestible organic matter (DOM) intake was 2.5, 2.7, 2.3 and 2.1 kg for cows fed on Bana, Mulato II, Piata and Xaraes respectively. The DOM intake was positively related to milk yield; thus, Xaraes had the lowest DOM intake and lowest milk yield. The milk yield from cows fed Piata was comparable to cows fed Bana (Figure 1).

Bana = Napier grass

Figure 1: Milk production from Jersey cows fed different *Urochloa* grasses and Napier grass in coastal lowlands, Kenya
**On farm study**

Out of the 18 farmers who registered for the feeding trial, only data from 12 farms with adequate *Urochloa* to last one week were analysed. Farmers used Piata, Xaraes, MG4 and Basilisk depending on what they had planted. Milk production increased from 4 to 4.6 litres/cow per day for low yielding animals, representing a 15% increase and from 9 to 12.6 litres/cow per day for the relatively higher yielding dairy cattle representing a 40% increase (Figure 2). This indicates that *Urochloa* is superior to the locally available feeds used by the farmers in the area during the study period.

**Figure 2:** Milk yield from cows fed local feeds or *Urochloa*

---

**Conclusion**

Urochloa accessions Piata and Mulato have potential to replace Bana in dairy feeding especially in areas where it is threatened by head smut and stunting disease.

**Acknowledgements**

The study was a collaborative undertaking between KALRO and Biosciences eastern and central Africa - International Livestock Research Institute (Beca-ILRI Hub) and was funded by Swedish International Development Agency (Sida). The Director General KALRO is acknowledged for the enabling environment in the organization which allowed for collaboration of scientists from KALRO Katumani and Mtwapa.

---

**References**


Productivity and nutritive value of *Urochloa* grass cultivars in semi-arid tropical Kenya

Njarui, D.M.G.¹ and Gatheru, M.
Kenya Agricultural and Livestock Research Organization
P.O. Box 340 – 90100 Machakos, Kenya
¹Corresponding author: donaldnjarui@yahoo.com

Key words: Urochloa, brachiaria, dry matter yield, crude protein, forage quality composition, *in-vitro* dry matter digestibility, plant tillers.

Abstract
There is increasing demand for high yielding and nutritious forages to meet the growing dairy farming in semi-arid Kenya. The productivity and nutritive value of seven *Urochloa* grass cultivars (*Urochloa decumbens* cv. Basilisk, *U. brizantha* cvs. Marandu, MG4, Piatá and Xaraes, *U. humidicola* cv. Llanero and *U. hybrid* cv. Mulato II) were evaluated in two diverse semi-arid environments, Katumani and Ithookwe in Kenya. At Katumani, the dry matter (DM) yield (5000 - 7500 kg/ha) was highest during the first harvest during the long rains (LR) 2014 season. Dry matter yield declined progressively with season and in the third season (LR 2015) only Xaraes achieved over 2000 kg/ha. All *Urochloa* cultivars died and no yield was recorded after the third harvesting season (LR 2015) due to prolonged dry season. At Ithookwe, all plants survived during the period of evaluation. Generally the DM yield was highest (4200 – 9200 kg/ha) in the second harvesting season during short rains (SR) 2014 with Llanero having the highest yield and Mulato II the lowest. Significant differences (*P* < 0.05) in forage quality was recorded in calcium, phosphorus, ash, neutral detergent fibres (NDF) and lignin content. However, none of the cultivars consistently contained more than the other cultivars in all the forage quality parameters analysed. The cv. Xaraes had the highest calcium content and Marandu had the lowest while MG-4 contained the highest phosphorus and Basilisk the lowest. Mulato II contained the highest crude protein and lowest NDF. The study revealed that *Urochloa* could increase forage resources in the semi-arid regions of Kenya where annual rainfall exceed 700 mm without prolonged dry season.

Introduction
The rapid growth in demand of milk and other dairy product has presented an opportunity for expansion of dairy farming in semi-arid areas of Kenya. In the semi-arid eastern midlands of Kenya, Napier grass (*Pennisetum purpureum* Schum.) is the most widely cultivated fodder by the dairy farmers in the hill masses where it is relatively wetter but is not drought tolerant. Due to continuous cultivation for a long time, it has become susceptible to Napier stunting and head smut diseases. Napier stunt causes herbage yield reduction of 40 - 90% (Mulaa *et al.*, 2004) and 35% milk reduction while head smut causes yield loss of 25 - 46% (Mwendia *et al.*, 2006). There is need for other forages that are drought tolerant and persistence to support livestock productivity. *Urochloa* (commonly known as brachiaria) grass offers an alternative potential to bridge the gap to increase feed availability. *Urochloa* grass is adapted to infertile acid soils, is highly productive and nutritious for livestock feed (Ghimire *et al.*, 2015). Moreover, it has potential to mitigation climate change through carbon sequestration and provides other ecosystem benefits (Dijkenk *et al.*, 2014). *Urochloa* is widely cultivated in Australia, South America and part of South East Asia supporting a highly vibrant beef industry. Despite the widespread distribution of the genus *Urochloa* in Kenya, with 33 documented species, it has been underutilized for livestock production due to limited research. Nguku *et al.*, (2016 ) recommended evaluation for several seasons to assess it productivity with the semi-arid region of Kenya. The objective of the study was to evaluate the productivity and nutritive value of seven *Urochloa* grass cultivars in diverse drought prone region of eastern midlands tropics of semi-arid Kenya.
Methods
The study was conducted at Katumani (1°35′S, 37°14′E) and Ithookwe (1°37′S, 38°02′E) in the eastern midlands of Kenya. Katumani is located at higher altitude (1600 m) than Ithookwe (1160 m) but mean temperature is lower (19.6°C) than Ithookwe (22.5°C). Ithookwe receives higher mean annual rainfall (1010 mm) than Katumani (700 mm). The rainfall in both sites is bimodal, with the long rains (LR) occurring from March to May and short rains (SR) from October to December, is generally erratic with frequent droughts. The soil ranges from Chromic luvisols to is red sandy earth.

The Urochloa grass cultivars evaluated were Urochloa decumbens cv. Basilisk (CIAT 606), U. brizantha cvs. Marandu (CIAT 6294), Xaraes (CIAT 26110), Piata (CIAT 16125), MG-4 (CIAT 26646), U. humidicola cv. Llanero (CIAT 6133) and U. hybrid cv. Mulato II (CIAT 36087).

The grasses were planted in plots of 4 x 5 m in a randomized complete block design with 3 replications. The seeds were sown during the SR season in November 2013, following the recommended practice. Triple super phosphate (TSP 46% P₂O₅) fertilizer was applied during planting at a rate of 40 kg/ha P while calcium ammonium nitrate (CAN, 26% N) was top-dressed during the production phase at 100 kg N/ha per year.

To stimulate uniform growth, a standardisation cut was made after the end of the first wet season (SR 2013). Sampling for DM yield began from second wet season during LR 2014 season in which the plants were repeatedly harvested after every 8 weeks from an area of 2 x 2 m. During the same time, the tiller numbers were counted from an area of 1 x 1 m. The materials for DM determination were dried at 105°C for 48 hours and those for forage quality analysis at 65°C for approximately 72 hours. Due to relatively high cost of analysis, only samples harvested during the LR 2014 season at Katumani were analysed for nutritive quality using the standard procedures. The DM yields for each season were pooled together before analysis. The data for each site was statistically analysed separately and mean separated using the least significant difference (LSD) test at $P < 0.05$. The DM yield for each season was regressed against respective total number of tillers within an area of 1 x 1 m.

Results

Dry matter production

Katumani: The DM yield for three wet seasons at Katumani is shown in Figure 1. All the cultivars failed to survive beyond the LR 2015 season thus no yields were recorded thereafter. The DM yield was highest during the first harvest (LR 2014) with all the cultivars attaining over 5000 kg/ha. Dry matter declined thereafter and during SR 2015 season, only Xaraes achieved over 2000 kg/ha. Significant difference ($P < 0.05$) on DM yield among the Urochloa grass was recorded during the SR 2014 and LR 2015 seasons. The cv. Xaraes produced the highest DM yield in both seasons while cvs. Llanero and Marandu had the lowest yield in SR 2014 and LR 2015 seasons, respectively.

Ithookwe: Unlike at Katumani, all cultivars survived during the period of evaluation and thus DM yield was recorded for four seasons (Figure 2). Significant difference in DM yields among the Urochloa grass occurred during the LR 2014 and SR 2014 seasons. However, DM yield was highest during the SR 2014 (4200 – 9200 kg/ha) with Llanero having the highest yield and Mulato II the lowest. In the other seasons, all the cultivars achieved over 3000 kg/ha except Marandu and Mulato II which had less than 3000 kg/ha.

Effect of tillers on dry matter yield

There was significant and positive correlation between DM yield and tiller development at Katumani ($r = 0.3766, P <0.001$) and Ithookwe ($r = 0.2141, P < 0.001$) which was evidenced by increased DM yield with increased number of tillers (Figure 3). At Katumani, the DM yield increased with increased tiller numbers during the period of the study while at Ithookwe, DM yield increased with increased number of tillers and tended to plateau after 500 tillers m².
**Figure 1:** Dry matter (DM) yield of *Urochloa* grass during: (a) long rains 2014, (b) short rains 2014 and (c) long rains 2015 at Katumani, eastern midlands, Kenya.

**Figure 2:** Dry matter (DM) yield of *Urochloa* grass during: (a) long rains 2014, (b) short rains 2014, (c) long rains 2015 and (d) short rains 2015 seasons at Ithookwe, eastern midlands, Kenya.

**Figure 3:** The effect of number of tillers on dry matter yield of *Urochloa* grass at (a) Katumani and (b) Ithookwe.
Forage quality composition

Table 1 shows the results of forage quality analysis. There were marked differences \((P < 0.05)\) in the level of calcium, phosphorus, ash, neutral detergent fibres and lignin among the *Urochloa* cultivars. However, none of the cultivars consistently contained more of all the forage quality parameters than the other cultivars. For mineral levels, Xaraes had the highest calcium content and Marandu had the lowest while MG-4 contained the highest phosphorus and Basilisk the lowest. Mulato II contained the highest crude protein and lowest neutral detergent fibres. Llanero was more \((P < 0.05)\) lignified than the other *Urochloa* cultivars.

Table 4: Herbage chemical composition (% of DM) and digestibility of *Urochloa* cultivars at 8 weeks cutting interval at Katumani, eastern midlands of Kenya

<table>
<thead>
<tr>
<th><em>Urochloa</em> cultivars</th>
<th>Ca</th>
<th>P</th>
<th>Ash</th>
<th>(^1\text{CP})</th>
<th>(^2\text{NDF})</th>
<th>(^3\text{ADF})</th>
<th>(^4\text{ADL})</th>
<th>(^5\text{IVDMD})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xaraes</td>
<td>0.27⁴</td>
<td>0.11³</td>
<td>12.6⁵</td>
<td>9.6³</td>
<td>65.2⁴</td>
<td>35.4⁴</td>
<td>2.3³</td>
<td>56.14⁴</td>
</tr>
<tr>
<td>Piata</td>
<td>0.10⁴</td>
<td>0.11³</td>
<td>11.4⁵</td>
<td>8.9⁴</td>
<td>67.0⁴</td>
<td>40.8⁴</td>
<td>2.9³</td>
<td>56.09⁴</td>
</tr>
<tr>
<td>MG4</td>
<td>0.22⁴</td>
<td>0.14³</td>
<td>12.5⁵</td>
<td>8.0³</td>
<td>64.7⁴</td>
<td>38.6³</td>
<td>3.3³</td>
<td>56.89⁴</td>
</tr>
<tr>
<td>Llanero</td>
<td>0.17⁴</td>
<td>0.10³</td>
<td>11.4⁵</td>
<td>9.5⁴</td>
<td>66.6⁴</td>
<td>40.9⁴</td>
<td>4.4³</td>
<td>55.37³</td>
</tr>
<tr>
<td>Mulato II</td>
<td>0.13⁴</td>
<td>0.08³</td>
<td>15.0⁵</td>
<td>10.7³</td>
<td>60.6³</td>
<td>38.8³</td>
<td>2.6³</td>
<td>58.62³</td>
</tr>
<tr>
<td>Basilisk</td>
<td>0.11⁴</td>
<td>0.05³</td>
<td>12.1⁵</td>
<td>8.0³</td>
<td>68.1³</td>
<td>42.2³</td>
<td>3.4³</td>
<td>54.32³</td>
</tr>
<tr>
<td>Marandu</td>
<td>0.09³</td>
<td>0.08³</td>
<td>13.9⁵</td>
<td>9.2³</td>
<td>65.6³</td>
<td>38.8³</td>
<td>2.3³</td>
<td>48.19³</td>
</tr>
<tr>
<td>LSD ((P &lt; 0.05))</td>
<td>0.08</td>
<td>0.03</td>
<td>1.84</td>
<td>1.4</td>
<td>3.2</td>
<td>N.S.*</td>
<td>0.9</td>
<td>N.S. *</td>
</tr>
</tbody>
</table>

\(^1\text{CP}=\text{Crude protein}; \(^2\text{NDF}=\text{Neutral detergent fibre}; \(^3\text{ADF}=\text{Acid detergent fibre}; \(^4\text{ADL}=\text{Acid detergent lignin}; \(^5\text{IVDMD}=\text{in-vitro dry matter digestibility.} \)

Means with different superscript in the same column differ significantly at \(P < 0.05\)

*N.S. not significant

Discussion

The *Urochloa* grass cultivars differed in productivity between the sites with DM yield being higher at Ithookwe than at Katumani in all the seasons. This was attributed to the relatively higher rainfall at the Ithookwe site. However, the DM yields were low compared with those recorded by Pizarro *et al.*, (2013) in Asia but were similar to those recorded by Wassie *et al.*, (2016) in Ethiopia. The cvs. Llanero, Xaraes, Piata, MG-4 and Basilisk were the most productive in both sites. Mulato II and Marandu had the lowest yield in most of the harvests and this was mainly due to red spider mites attack. Tiller number had influence on the yield as shown by the positive correlation. Katumani site favoured development of more tillers compared with Ithookwe. High tiller number enhances resource use from the soil and recovery after defoliation. Nevertheless, high number of tillers can be detrimental under low rainfall as it lead to high evapo-transpiration and moisture loss. Unfortunately, the low rainfall was not sufficient to sustain excessive tillering ability at Katumani and this contributed to death of plants due to limited moisture availability after the LR 2015 season. The CP contents were low compared with those reported by Nyambati *et al.*, (2016) in the cooler and wetter highlands of central Kenya, Wassie *et al.*, (2018) in Ethiopia and Pizzarro *et al.*, (2013) in Asia. Nevertheless, all the *Urochloa* cultivars had CP content within the range of 9-12% that is regarded as highly palatable.

Despite the *Urochloa* cultivars showing poor survival under extreme climatic condition, when the dry season exceeded over 5 months with high temperatures, they can boost the forage resource base in the semi-arid regions of Kenya due to their consistently high yield in both sites. Although Mulato II had higher CP than the other cultivars, it is not recommended for cultivation in the region due to being susceptible to red spider mites pest. It should be noted that the *Urochloa* is unlikely to survive in areas that receives less than 700 mm annual rainfall with dry seasons exceeding five months. Further research is needed to quantify the feeding value of *Urochloa* cultivars on animal production performance.
References


Soil microbial carbon, nitrate and ammonium nitrogen dynamics in *Urochloa* grass cultivated in sub-humid Kenya

Ndung’u- Magiroi, K.W. 1*, Koech, M.N. 1, Mutoko, M.C. 1, Kamidi, M. 1, Gichangi, E.M. 2 and Njarui, D.M.G. 2

1Kenya Agricultural Research & Livestock Organization (KALRO) - Kitale, Kenya
2KALRO-Katumani, Kenya

*Corresponding author: kezialmagiroi@gmail.com

Abstract
A study was conducted to monitor the dynamics of available soil phosphorus (P), soil microbial biomass carbon (SMBC), nitrogen (SMBN), ammonium and nitrate nitrogen under seven *Urochloa* grass cultivars at Kitale, Kenya. The *Urochloa* cultivars: *Urochloa brizantha* cvs. Marandu, MG-4, Piata, Xaraes, *U. decumbens* cv. Basilisk, *U. hybrid* cv. Mulato II and *U. humidicola* cv. Llanero was compared with two popularly grown forages, Rhodes grass (*Chloris gayana* cv. KAT R3), Napier grass (*Pennisetum purpureum* cv. KK1) and annual weeds. The treatments were tested in a randomized complete block design arranged in a split plot treatment structure with two rates of fertilizer N (0 and 100 kg N ha\(^{-1}\) yr\(^{-1}\)) and P (0 and 40 kg P ha\(^{-1}\)) assigned to the main plots and the grass cultivars assigned to the subplots.

After 80 weeks, moist rhizosphere soil was sampled at 0 – 10 cm depth to determine microbial biomass. Application of fertilizer N and P did not significantly (P>0.05) influence SMBC, SMBN, ammonium N (NH\(_4^+\)N) and nitrate N (NO\(_3^-\)N). However, significant (P= 0.001) changes in soil properties, including NH\(_4^+\)N and NO\(_3^-\)N due to grass cultivars, were observed. After 80 weeks, the bare plot, annual weeds and Napier grass accumulated higher pools of ammonium and nitrate N, but the microbial biomass (SMBC and SMBN) in these treatments were lower than in *Urochloa* grasses. Soil pH was also low, while NO\(_3^-\)N was high indicating increased nitrification in the bare and Napier grass plots. Ammonium N was the most dominant form of inorganic N in Llanero and Piata due to increased plant uptake or reduced nitrification rates. The results suggested that the change in the SMBC and SMBN in the *Urochloa* grasses was regulated by the nitrate and ammonium N and soil pH.

Key words: Ammonium N, microbial biomass N, nitrate, soil organic matter, soil quality

Introduction
Continuous cultivation of land for crop production has generally altered key soil nutrient cycles especially nitrogen (N), and phosphorus (P) in Kenya. Sustainable management of soil by increasing or maintaining organic matter content is essential for increased pasture productivity. Changes in organic matter input or rate of decomposition are more readily determined from soil microbial biomass than the total organic matter (Powlson *et al.*, 1987). Assessment of soil microbial biomass indicates the impact of land use and management changes. Several authors have shown that the soil microbial biomass is higher in grass systems than in the open cultivated cropland because of the high turnover in pasture systems (McGonigles and Turner 2017). The dynamics of soil microbial biomass carbon (SMBC) and N (SMBN) have been used to determine the influence of different cropping systems on soil quality (Wu 2020). A study in Chinese sandy grasslands showed that addition of N over 5 years did not increase the soil organic C, total N and total P, but decreased soil pH, leading to lower microbial biomass (Li *et al.*, 2010). Although several studies have shown changes in SMBC and SMBN in cropping and grassland systems, information on the contribution of different grass varieties to soil quality is scanty. *Urochloa* grasses are productive and persistent even under low soil fertility conditions, but information of the effect of growing these grasses in low fertility soils is scanty. This study, conducted in a low fertility Acrisol in Kenya monitored the dynamics of NO\(_3^-\)N, NH\(_4^+\), SMBC and SMBN in different *Urochloa* grass cultivars under varying N and P management.
Materials and Methods
The trial was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Kitale, (1° 0’ 6.6” N and 34° 59’ 10” E) located within the sub humid highlands of Kenya. Seven Urochloa grass cultivars; Urochloa decumbens cv. Basilisk, U. brizantha cvs. Marandu, MG4, Piata, Xaraes, U. hybrid cv. Mulato II and U. humidicola cv. Llanero, two commonly grown grasses Rhodes grass (Chloris gayana cv. KAT R3) and Napier grass (Pennisetum purpureum cv. KK1) were included as positive controls, while a bare and annual weeds plot as negative controls. Treatments were applied to plots in a randomized complete block design and assigned in a split plot structure with four replications. The main plot treatment was a level of N (0, and 100 kg N ha⁻¹ yr⁻¹) and P (0 and 40 kg P ha⁻¹) fertilization while the grasses were assigned to the subplots. Triple superphosphate applied at the trial initiation provided P while calcium ammonium nitrate applied seasonally provided N. At 80 weeks after seedlings emergence, moist rhizosphere soil was sampled at 0 - 10 cm depth for determination of microbial biomass. Roots were sampled using the soil-core method (Bohm 1979) and root biomass calculated as a factor of the bulk density. The SMBC was determined by a fumigation extraction method according to (Vance et al., 1987). The SMBN was determined using Brookes et al., (1985), while NH₄⁺N and NO₃⁻N were determined as highlighted by Anderson and Ingram (1993). All measurements were analysed in triplicates and expressed as dry weight. Analysis of variance for split plot structure (p < 0.05) was undertaken to determine the effect of fertilizer N and P on microbial biomass, soil pH and available P using Statistix 10 package (Statistix 2003). Means were separated using the Tukey’s HD test. Where ANOVA was significant (P ≤ 0.05), Pearson correlation was performed to assess relationships between the soil microbial biomass, N and available P.

Results
Table 1 shows the effect of Urochloa grass on available P and soil microbial properties. Basal application of P and seasonal topdressing with N did not significantly (p≤0.05) influence the SMBN, SMBN, available P and NH₄⁺N in soil. The available P accumulated in the soil was variable, with no differences among the grass varieties. The SMBN and SMBN were generally higher in the Urochloa grasses than in the controls (bare plot, annual weeds, Rhodes and Napier grass). Within the trial period, the SMBN accumulated in the soil was lower (91-124 mg N/ kg soil) than that reported (121 - 200 mg N/ kg soil) in the eastern drylands, Kenya by Gichangi et al., (2016). Llanero, Marandu and Piata accumulated lower NO₃⁻N compared to NH₄⁺N with higher NH₄⁺N: NO₃⁻N ratio and increased soil pH (6.05 – 6.12). The NH₄⁺⁻N:NO₃⁻N ratio compares the level of NH₄⁺⁻N to each NO₃⁻N accumulated in the soil. A high NH₄⁺⁻N compared to NO₃⁻N ratio shows increased NH₄⁺⁻N accumulation by the corresponding cultivar. The bare plot, Basilisk, MG-4, Mulato II, Xaraes, Rhodes and Napier grass had lower NH₄⁺⁻N:NO₃⁻N ratio and lower soil pH showing higher conversion of ammonium to nitrates. Other cultivars such as Llanero, Marandu and Piata had accumulated lower NO₃⁻N compared to NH₄⁺⁻N with higher NH₄⁺⁻N: NO₃⁻N ratio that may indicate lower nitrification.

Table 1: Soil microbial biomass C and N, Ammonium and nitrate N under N and P fertilized Urochloa grasses in Kitale

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Microbial biomass C (mg C/ kgₕₒₒ)</th>
<th>Microbial biomass N (mg N/kgₕₒₒ)</th>
<th>NH₄⁺⁻N (mg N/kg)</th>
<th>NO₃⁻N (mg N/kg)</th>
<th>Shoot: root ratio</th>
<th>Available P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare plot</td>
<td>103</td>
<td>7.4</td>
<td>13.4</td>
<td>13.9</td>
<td>0</td>
<td>15.0</td>
</tr>
<tr>
<td>Annual weeds</td>
<td>107</td>
<td>7.6</td>
<td>10.2</td>
<td>8.6</td>
<td>1.7</td>
<td>19.2</td>
</tr>
<tr>
<td>Basilisk</td>
<td>91</td>
<td>5.6</td>
<td>8.1</td>
<td>6.6</td>
<td>3.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Llanero</td>
<td>128</td>
<td>9.6</td>
<td>12.1</td>
<td>4.7</td>
<td>1.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Marandu</td>
<td>121</td>
<td>9.3</td>
<td>8.9</td>
<td>4.2</td>
<td>2.5:1</td>
<td>17.5</td>
</tr>
<tr>
<td>MG4</td>
<td>102</td>
<td>7.1</td>
<td>9.6</td>
<td>7.6</td>
<td>3.6:1</td>
<td>15.8</td>
</tr>
<tr>
<td>Mulato II</td>
<td>124</td>
<td>9.2</td>
<td>6.9</td>
<td>5.4</td>
<td>2:1</td>
<td>16.7</td>
</tr>
<tr>
<td>Piata</td>
<td>110</td>
<td>8.0</td>
<td>9.6</td>
<td>4.9</td>
<td>2.5:1</td>
<td>15.0</td>
</tr>
<tr>
<td>Xaraes</td>
<td>113</td>
<td>8.2</td>
<td>7.3</td>
<td>4.9</td>
<td>2.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Rhodes grass</td>
<td>114</td>
<td>5.5</td>
<td>9.5</td>
<td>7.5</td>
<td>4.2</td>
<td>14.2</td>
</tr>
<tr>
<td>Nappier grass</td>
<td>111</td>
<td>5.9</td>
<td>11.2</td>
<td>8.4</td>
<td>6.0</td>
<td>18.3</td>
</tr>
<tr>
<td>Mean</td>
<td>111.3</td>
<td>7.5</td>
<td>9.70</td>
<td>6.98</td>
<td></td>
<td>16.25</td>
</tr>
<tr>
<td>SED (P=0.05)</td>
<td>Ns</td>
<td>Ns</td>
<td>1.85</td>
<td>1.85</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

Where ns- not significant at P ≤ 0.05
The significant negative relationship between SMBC and NH$_4^+$N and NO$_3^-$N was noted, suggesting that NH$_4^+$N and NO$_3^-$N decreased with an increase in microbial biomass (Table 2). However, the root biomass did not influence microbial biomass and soil nutrients. NH$_4^+$N and NO$_3^-$N were significantly (P = 0.034) influenced by the grass cultivars. The pools of NH$_4^+$N and NO$_3^-$N were higher in the bare plot, annual weeds and Napier grass which also accumulated lower SMBC. Ammonium N was the most dominant form of inorganic N in Llanero, Marandu and Piata. These cultivars also had lower NO$_3^-$N, SMBC and SMBN, indicating either low nitrification rates or a high rate of NO$_3^-$N uptake by plants.

Table 2: Pearson correlation between microbial biomass and root biomass in Kitale

<table>
<thead>
<tr>
<th></th>
<th>NH$_4^+$N</th>
<th>NO$_3^-$N</th>
<th>pH</th>
<th>P</th>
<th>SMBC</th>
<th>SMBN</th>
<th>RB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3^-$N</td>
<td>0.65*</td>
<td>0.68**</td>
<td></td>
<td>-0.84***</td>
<td>0.66*</td>
<td>-0.07</td>
<td>1</td>
</tr>
<tr>
<td>pH</td>
<td>-0.44</td>
<td>0.02</td>
<td>0.16</td>
<td>1</td>
<td>-0.31</td>
<td>0.17</td>
<td>-0.09</td>
</tr>
<tr>
<td>P</td>
<td>0.135</td>
<td>0.69*</td>
<td>-0.68*</td>
<td>0.02</td>
<td>-0.03</td>
<td>0.83**</td>
<td>1</td>
</tr>
<tr>
<td>MBC</td>
<td>-0.79**</td>
<td>-0.52</td>
<td>0.60*</td>
<td>-0.03</td>
<td>0.17</td>
<td>-0.09</td>
<td>1</td>
</tr>
<tr>
<td>MBN</td>
<td>-0.11</td>
<td>-0.45</td>
<td>0.02</td>
<td>-0.31</td>
<td>0.17</td>
<td>-0.09</td>
<td>1</td>
</tr>
</tbody>
</table>

Where * - P≤0.05; NH$_4^+$N - Ammonium N; pH- Soil pH; NO$_3^-$N – Nitrate N; P – Available P; SMBC- soil microbial biomass C; SMBN- soil microbial biomass N; RB- Root biomass sampled at 80 weeks after emergence

Discussion [Conclusions/Implications].

As a source and sink for plant nutrients, soil microbial biomass has been proposed as a sensitive indicator of changes in soil properties (Nannipieri et al., 2003). The availability of organic C, the primary source of nutrients for microorganisms, influences the size of microbial biomass C and N. In this study, all the shoot biomass was cut and removed from the plots to mimic the common practice of cut and carry forage management system, suggesting that root exudates contributed to SMBC. Hence, the differences in SMBC and SMBN accumulated by the grass cultivars were minimal. Lower decomposition rates in this humid climate reduced the amount of SMBC and N accumulated in the grasses compared to the levels reported in warm climates by Gichangi et al. (2016).

Nitrification is a biological process that converts NH$_4^+$N to NO$_3^-$N, creating acidification in the process as noted in the bare, Mulato II, Napier and Rhodes grass plots. The current study suggests that the grasses with lower NH$_4^+$N:NO$_3^-$N did not inhibit nitrification in the rhizosphere, contributing to higher N losses through leaching and denitrification. Llanero was the most effective in improving soil pH, probably from suppression of nitrification, confirming the results by Ishikawa et al., (2003). To minimize nitrification and reduce N loss in agricultural or pasture areas, it is necessary to maintain soil N in the form of NH$_4^+$N for as long as possible to synchronize N fertilizer supply and the plant demand (Ishikawa et al., 2003). Fernandes et al., (2011) obtained similar results, who reported increased NO$_3^-$N and lower or similar levels of NH$_4^+$N in U. decumbens and U. ruziensis. Authors such as Sylvester-Bradley et al., (1988) and Ishikawa et al., (2003) also observed that U. decumbens do not inhibit nitrification as reported for U. humidicola. In conclusion, our study showed that when low levels of N and P is applied in low fertility soils, the Urochloa varieties did not accumulate significant SMBC, SMBN and available P. However, Llanero accumulated higher ammonium in the soil, implying reduced losses of the highly mobile NO$_3^-$N. The results in this study suggested that the change in the SMBC and SMBN in the Urochloa grasses was regulated by the nitrate and ammonium N and soil pH. Further study is suggested to test the effects of retention of shoot biomass on SMBC and SMBN and other soil properties in this humid region.

Acknowledgements

The authors are grateful to the Swedish International Development Agency (Sida) for funding this work. The collaboration between KALRO and the Biosciences eastern and central Africa -International Livestock Research Institute (BecA-ILRI) Hub is highly appreciated.
References


THEME 3: LIVESTOCK PRODUCTION SYSTEMS

Topic: Beef and Dairy Production Systems
Management strategies for enhanced beef production on suckler cow farms

Asheim, L.J.¹; Aass, L.²; Åby, B.².
¹Norwegian Institute of Bio-economy Research, P.O Box 115, 1432 Ås;
²Institute of Animal and Aquaculture Sciences, Norwegian University of Life Sciences.

Key words: suckler cows; management strategies; breeds; agricultural area; NH3-treated straw

Abstract
While around two thirds the Norwegian beef is produced on dairy cow farms, meat production on specialized beef farms has increased in recent years. The specialized beef industry consists of suckler cow herds producing calves, and farm operations that purchase weaned calves for fattening. A linear programming (LP) model of suckler cow herds, selling weaned calves at 200 days, was developed to study the influence of certain management strategies on profitability. The data were derived from the records of 31 suckler cow herds from three Norwegian regions. The feed costs for silage (roughly half of the feed), NH3-treated straw, concentrate and farm and range pastures were calculated and used as model input. In the model pasture could account for as much as half of the annual feed intake with spring calving on small British breeds and 30% with autumn calving on large continental breeds. In region 1 and 2 in south Norway, late harvesting of roughages and using NH3 treated straw was advantageous compared to earlier harvesting and less concentrates. The growth rate of calves was demonstrated to be an important parameter for the economy in both British and continental breeds. Shortening age at first calving to 2 years, and the calving interval to 12 months was profitable but the gains were small. Similarly, the front-end loading concept with 2/3 of the calves after the first ovulation period, and the remaining in the next, was profitable compared to a similar number (1/3) in three subsequent periods. The economics of a high or low replacement rate was also examined.

Introduction
The beef industry in Norway is investigating ways to improve profitability. The industry consists of suckler cow herds producing calves for fattening on the farm or sale, and a small number of farm operations purchasing weaned calves for fattening indoors. Steers are uncommon, less than one percent. In a sample of 31 herds, silage constituted roughly half of the feed energy, NH3 treated straw 5%, concentrates 8%, and the rest was pasture. Pasture constituted 30.7% of the energy for continental breeds and 44.5% for the smaller British breeds (Wetlesen 2020). Most beef farmers have access to farm pasture and many also use outfield rangelands, however pasture intake is limited by the short grazing period (approx. 4 mo.). Late winter calving was reported to be advantageous on alpine or sub-alpine pastures in Switzerland (Estermann et al., 2003) and was practiced by more than 90% of the Norwegian suckler cow farmers (Wetlesen 2020). Utilizing heterosis effects by cross breeding and rotational crossings require that the cow has many calves and a long lifetime. However, the cows increase weight in their third year after receiving the first calf at two years of age (Animalia 2013). By slaughtering cows after two or three calvings, one maximizes cow meat production in proportion to the production on the offspring. Suckler cows should not be slaughtered before the last calf is weaned. In Norwegian data calves from primiparous cows are usually heavier than later born calves, but on the other hand there are more birth difficulties and higher mortality for the first calf (Animalia 2013). Furthermore, after the calving it takes longer, 80-100 d., before the first calving cows show heat versus 35-70 d. for older cows, increasing the likelihood that subsequent calves will be born late relative to pasture time. In a pure breed herd, the replacement rate can be as low as 0.10 if the cow gets 10 calves and is slaughtered at 11.5 years. If the cows are slaughtered after 2-3 calves the rate can reach 0.50.
The objectives of the study were to investigate and compare management strategies to improve the economy in suckler cow beef production systems under Norwegian conditions.

Materials and Methods

The analysis dealt with suckler cow herds with calving time in late winter or in the spring and selling six months old (weaned) calves in the fall. For pregnant cows late harvested silage with high fibre content or NH3-treated straw can be used as winter feed. NH3-treated straw must be supported with protein concentrate or earlier harvested silage. NH3 treated straw and pasture were cheaper per energy unit, than baled silage. The feeding value of silage was determined by its digestibility and positively correlated with changes in slaughter weights for beef cattle (Keady et al., 2013). Mating most of the heifers and slaughter those who do not get pregnant early enough, was compared to slaughtering most heifers and keeping suckler cows in production longer. Additionally, the economics of small British breeds with larger continental breeds and the economics of high and low growth for calves were compared under Norwegian conditions. The following strategies were examined:

1. Using NH3-treated straw with concentrates or early harvested silage as winterfeed.
2. Increasing calf survival, vitality and growth with concentrated calving period (front-end principle).
3. Extensive slaughtering of heifers or young cows after their first calf.
4. Comparing the economics of high and low replacement rates.

The analysis was based on initial calving age being around 2 years which, according to Nelson (2016), is more cost efficient than three years. Reducing calving age, calving interval, and a more concentrated calving period (CCP) can be achieved by targeted synchronization of heat and ovulation, and by improved winter feeding. The CCP or front-end concept mean that at least 60-65% of the calvings should occur following the first ovulation period (21 days). The remaining 35-40% should be in the next period. The rationale for this is that the earliest born calves are less prone to infectious diseases since the environment is less infected. Such calves will be larger than later-born calves at weaning. The economics of the CCP principle was compared to one third of the calvings in each of three subsequent 21 days periods, starting at the same time. It was assumed that the losses of calves up to 180 days can be lowered by 0.5 percentage points and the pasture uptake increased due to better synchronisation of calving time and pasture growth as more animals could be released in time. Additionally, the growth rate of calves also may increase due to lower infection pressure and better vitality.

An LP model, with procedure as explained in Luenberger and Ye (1984), was set up to maximize Gross Margins (GM) of a suckler cow farm selling weaned 6 months old calves. The model was parameterized with economic and production data from 31 farm records from a) Grain areas (12), b) Rural valley and mountainous areas in Eastern and Mid-Norway (10), and c) Northern Norway (9) (Table 1). Average time of calving was stipulated to February 28 in the grain areas and March 21 in the other areas based on length of the grazing season. The cost of the roughages per feeding unit of energy (FEm\(^1\)), both silage and NH3 treated straw, including baling and plastic for preservation, as well as farm and range pastures were calculated based on data from the farms and used as model input.

<table>
<thead>
<tr>
<th></th>
<th>Grain areas</th>
<th>Valley and mountain areas</th>
<th>Northern Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadows and farm pasture, ha</td>
<td>60.9</td>
<td>36.5</td>
<td>56.1</td>
</tr>
<tr>
<td>Yields, FEm/ha</td>
<td>4,800</td>
<td>4,220</td>
<td>3,650</td>
</tr>
<tr>
<td>Area and landscape support, NOK*/ha</td>
<td>1,390</td>
<td>3,710</td>
<td>3,680</td>
</tr>
<tr>
<td>Farm pasture, NOK*/FEm</td>
<td>1.38</td>
<td>1.01</td>
<td>1.14</td>
</tr>
<tr>
<td>Range pasture, NOK*/FEm</td>
<td>0.32</td>
<td>0.35</td>
<td>0.85</td>
</tr>
<tr>
<td>NH3-treated straw, NOK*/FEm</td>
<td>2.33</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>Straw not used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baled silage, NOK*/FEm</td>
<td>2.49</td>
<td>2.88</td>
<td>2.14</td>
</tr>
</tbody>
</table>

*Norwegian kroner, \(1 \text{ €} = 8.08 \text{ NOK}\)

Feeding unit milk, 1 FEm=6.9 Mega Joule (MJ) of net energy
The costs of early harvested silage, NOK 2.76/FEm in the grain areas and 3.29/FEm in valley and mountain areas, were assessed based on Flaten et al., (2015). Early harvesting of meadows raised the costs since yields were lower. It was possible to graze meadow and the costs of such pasture were set to the average of cost silage and farm pasture. The annual feed requirements in FEm (winterfeed in brackets) were 3,727 (2,322) and 3,449 (2,551) for high and low growing British breeds and similarly 4,706 (2,622) and 4,199 (3,164) for continental breeds. The income from the suckler cows were the sum from sale of the calf and discarded cows, depending on replacement rates, and different support and supplementary payments. The fixed costs of the barn were not considered but fences were incorporated in the costs of pastures. The amounts of outfield range pastures were limited due to lack of areas in the grain areas and moderate in Northern Norway due to the short grazing season.

Results
The smaller British breeds were more profitable than the larger continental breeds in all the regions, but the continental breeds competed better in the grain areas (Table 2). Using concentrate feed to supplement farm production of roughages was profitable in all regions, particularly in Northern Norway where it was supplemented both in the pasture and indoor seasons for both breeds. In the other regions concentrate was supplemented only in the winter for the British breeds. Using NH3-straw was profitable in the grain areas and in the nearby valley and mountain areas. While some concentrate is necessary to supplement straw feeding it is not much and not an argument against using straw. However, it was not profitable to supplement straw with more protein rich early harvested silage instead of concentrates. What drives the use of concentrates in the model is the need for more feed than what can be provided by the own farm area.

The Gross Margins were the highest per cow in the grain areas, mainly due to lower costs. Including the support payments, the farms in Northern Norway had the highest per cow income, mainly due to the higher rates for area and landscape support and partly also the support for animals in the region (Table 2). Although the income per cow was somewhat higher for the continental breeds, they also used more concentrates and the farm area gave space for fewer animals, resulting in a poorer economic result.

Table 2: Costs, revenues, and Gross Margins (Norw. kroner) for British (B) and continental (C) breeds.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Grain areas</th>
<th></th>
<th>Valley and mountain areas</th>
<th></th>
<th>Northern Norway</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Suckler cows, No</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>71</td>
<td>52</td>
<td>44</td>
<td>74</td>
<td>53</td>
</tr>
<tr>
<td>Meadows and pasture</td>
<td>467,992</td>
<td>466,967</td>
<td>334,931</td>
<td>335,491</td>
<td>259,203</td>
<td>224,948</td>
</tr>
<tr>
<td>NH3-straw</td>
<td>65,222</td>
<td>63,607</td>
<td>38,170</td>
<td>37,593</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Concentrates</td>
<td>74,607</td>
<td>135,064</td>
<td>48,958</td>
<td>86,636</td>
<td>363,914</td>
<td>434,778</td>
</tr>
<tr>
<td>Meat and breeding animals</td>
<td>947,190</td>
<td>894,095</td>
<td>605,170</td>
<td>570,263</td>
<td>875,844</td>
<td>698,096</td>
</tr>
<tr>
<td>Area support</td>
<td>84,564</td>
<td>84,564</td>
<td>135,189</td>
<td>135,189</td>
<td>206,640</td>
<td>206,640</td>
</tr>
<tr>
<td>Support for animals</td>
<td>286,280</td>
<td>286,280</td>
<td>300,280</td>
<td>273,779</td>
<td>300,280</td>
<td>300,280</td>
</tr>
<tr>
<td>Gross Margin</td>
<td>552,644</td>
<td>441,028</td>
<td>564,531</td>
<td>465,778</td>
<td>644,649</td>
<td>487,921</td>
</tr>
</tbody>
</table>

A more concentrated period of calving was profitable particularly for continental breeds and in Northern Norway due to better use of pastures and less concentrate in the grazing season (Table 3). For farms with British breeds in the other areas only the lower losses of calves affected the optimal solutions. However, improved growth due to lower infection pressure was not factored in. The number of cows were unchanged or showed a small decrease in the alternatives with the more concentrated front-end calving time.
this leads to less area for winter feed and fewer animals. Only farms in the grain and in the valley and mountain areas with British breeds had better result with high growth. For continental breeds, there was a significantly higher resource input with high growth, and the higher income per cow was not sufficient to compensate for this.

The proportion of heifer calves varies so in practice this leads to less area for winter feed and fewer animals. Only farms in the grain and in the valley and mountain areas with British breeds had better result with high growth. For continental breeds, there was a significantly higher resource input with high growth, and the higher income per cow was not sufficient to compensate for this.

The lifespan of the cows will increase. Cows that have had two calves will not receive a young cow supplementary payment but will be 3.5 years old and reach high slaughter weight. As a larger part of the calves will be from primiparous cows, 1/3 (33%) for 3 calves compared to 1/8 (12.5%) for 8 calves the chance of calving difficulties and calf mortality increases and lower the profitability in this system.

The use of pasture was higher in the alternatives with high calf growth and as this can be difficult to supply it led to smaller herds (Table 3). Pasture intake can increase by grazing the meadows, but relatively little so straw feeding is not a reason for high concentrate use by suckler cows. However, was not profitable to harvest roughage early as an alternative to concentrates. In the model it was not possible to purchase bales of silage this option would likely have led to solutions with less use of concentrates, especially in Northern Norway. An important point is that the profitability of suckler cow production decreases when one exceeds the limit for supplementary payments, in Norway at 50 cows. It is then probably more profitable to fatten more calves than having more cows.

To increase meat production the focus of the management should be on the reproductive ability of the cow such as number of calves born and born alive. This should be encouraged, as the profitability of this system depends on this ability. The use of pasture was higher in the alternatives with high calf growth and as this can be difficult to supply it led to smaller herds (Table 3). Pasture intake can increase by grazing the meadows, but relatively little so straw feeding is not a reason for high concentrate use by suckler cows. However, was not profitable to harvest roughage early as an alternative to concentrates. In the model it was not possible to purchase bales of silage this option would likely have led to solutions with less use of concentrates, especially in Northern Norway. An important point is that the profitability of suckler cow production decreases when one exceeds the limit for supplementary payments, in Norway at 50 cows. It is then probably more profitable to fatten more calves than having more cows.

To increase meat production the focus of the management should be on the reproductive ability of the cow such as number of calves born and

### Table 3. Gross Margins with spread and front-end loaded calving and high and low growth for British and continental breeds. Norwegian kroner. Number of cows in parenthesis

<table>
<thead>
<tr>
<th>Breed</th>
<th>Grain areas</th>
<th>Valley and mountain areas</th>
<th>Northern Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>British breeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Margin spread calving</td>
<td>552,664 (84)</td>
<td>564,531 (52)</td>
<td>644,649 (74)</td>
</tr>
<tr>
<td>Gross Margin front-end calving</td>
<td>556,815 (84)</td>
<td>567,132 (52)</td>
<td>661,737 (71)</td>
</tr>
<tr>
<td>High growth, Gross Margin</td>
<td>554,461 (79)</td>
<td>569,219 (49)</td>
<td>604,111 (78)</td>
</tr>
<tr>
<td>Low growth, Gross Margin</td>
<td>552,114 (89)</td>
<td>543,983 (64)</td>
<td>651,945 (77)</td>
</tr>
<tr>
<td>Continental breeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Margin spread calving</td>
<td>441,028 (71)</td>
<td>465,778 (44)</td>
<td>487,921 (53)</td>
</tr>
<tr>
<td>Gross Margin front-end calving</td>
<td>453,288 (70)</td>
<td>477,344 (44)</td>
<td>529,734 (53)</td>
</tr>
<tr>
<td>High growth, Gross Margin</td>
<td>373,222 (53)</td>
<td>399,150 (43)</td>
<td>393,508 (53)</td>
</tr>
<tr>
<td>Low growth, Gross Margin</td>
<td>471,409 (76)</td>
<td>483,681 (53)</td>
<td>574,819 (67)</td>
</tr>
</tbody>
</table>

The use of pasture was higher in the alternatives with high calf growth and as this can be difficult to supply it led to smaller herds (Table 3). Pasture intake can increase by grazing the meadows, but relatively little so straw feeding is not a reason for high concentrate use by suckler cows. However, was not profitable to harvest roughage early as an alternative to concentrates. In the model it was not possible to purchase bales of silage this option would likely have led to solutions with less use of concentrates, especially in Northern Norway. An important point is that the profitability of suckler cow production decreases when one exceeds the limit for supplementary payments, in Norway at 50 cows. It is then probably more profitable to fatten more calves than having more cows.

To increase meat production the focus of the management should be on the reproductive ability of the cow such as number of calves born and

### Table 4: Gross Margins (Norw. kroner) for suckler cow operations according to number of calvings.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Grain areas</th>
<th>Valley and mountain areas</th>
<th>Northern Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic, 8 calvings</td>
<td>552,644</td>
<td>441,028</td>
<td>564,531</td>
</tr>
<tr>
<td>Alt. 1, 6 calvings</td>
<td>557,652</td>
<td>447,877</td>
<td>572,971</td>
</tr>
<tr>
<td>Alt. 2, 4 calvings</td>
<td>567,067</td>
<td>458,217</td>
<td>587,780</td>
</tr>
<tr>
<td>Alt.3, 3 calvings</td>
<td>575,666</td>
<td>467,626</td>
<td>600,791</td>
</tr>
</tbody>
</table>
calf viability and growth. Increasing frequency of twin births, fewer stillborn calves and better calf vitality are obvious factors, but measures to improve them can be difficult to identify. Narrowing and concentration of the calving time is interesting to reduce calf losses and improve growth of the calf since the infection pressure is lowered. There are also work-related benefits and better synchronization of feed requirement for the suckler cow and the calf relative to pasture production. Feeding all heifers calves and slaughter them as young cows instead of heifers or reduction of years in production and the number of calves before slaughter of suckler cows seems profitable due to better utilization of the growth ability of the young cows. However, utilizing heterosis effects requires that the cows have many calves during their lifetime.

Acknowledgements
The authors are grateful to the Research council of Norway and the farmers’ cooperative slaughterhouse Nortura for funding the study.

References


**Progardes® Desmanthus: good for beef, good for the environment**

**Gardiner, C**, **Mwangi, F**, **Charmley, E**, **Hall, T**, **Suybeng, B**, **Walker, G**

1 James Cook University, Townsville, Queensland 4811, Australia  
2 CSIRO, Townsville, Queensland 4811, Australia  
3 Consultant, 75 Love Road, Vale View, Queensland 4352, Australia  
*Corresponding author email: christopher.gardiner@jcu.edu.au*

Key words: beef production; antimethanogenic; liveweight gain; vertosol; progardes desmanthus

**Abstract**

The project “New pastures to increase livestock productivity across the north” is a four year project with a focus on the pasture legume Progardes® Desmanthus. The project explores: methodologies of legume establishment in grass pastures; the antimethanogenic properties of Desmanthus; botanical composition; soil sciences; and pasture nutritive value as related to beef production and meat sciences. Northern Australia has a substantial beef industry based predominantly on poor quality native grass pasture in a semiarid tropical environment with highly variable rainfall. This region also has very extensive areas of Vertosol soils with few, if any, well adapted sown pasture legumes. Progardes® (a blend of selected Desmanthus cultivars) has shown potential in these environments. The introduction of an adapted, high quality, grazing tolerant legume will bring livestock productivity and environmental gains to the region. Early results indicate establishment success of Progardes® has varied depending on establishment method, grass competition and rainfall; Two cultivars have reduced methane production by 10% compared to Rhodes grass in metabolic chambers; the role of tannins in the antimethanogenic properties of Desmanthus is under evaluation; a number of new accessions of Desmanthus show agronomic promise; grazing of commercial paired paddocks with and without Progardes has commenced with steer live weight gains at one site being an additional 0.173kg/hd/day live weight gain with the legume, compared to the grass only pasture; botanical composition via the BOTANAL methodology shows the paddocks contain 8 to 12% Progardes® by weight in the legume paddocks. Preliminary plant nutrition omissions trials indicate Progardes is responsive to P fertilisation on soils containing <9 mg of bicarbonate-extractable P/kg, with Zn, S and Fe supplementation also benefitting growth on some high-pH soils.

**Introduction**

The CRC-P project “New pastures to increase livestock productivity across the north” is a four year project partnership focused on the northern Australian beef sector involving privately owned and corporate beef producer companies, Universities (JCU and UWA), CSIRO, QDAF, MLA and is managed by Agrimix Pastures. The project is multifaceted with agronomic, botanical composition, soils, nutrition and animal production components. The project has a focus on legumes for the semiarid tropical regions of Northern Australia and is particularly focused on the vast Vertosol soil land types (Figure 1a) such as the Brigalow, Mitchell Grass Down, Gidgee and Gulf Plains regions where typically *Bos indicus* cattle graze predominately native grasslands. The Brigalow region also comprises the introduced buffel grass (*Cenchrus ciliaris*). For much of the year there is a dry season protein drought causing poor animal production as these native grasslands are of poor nutritional value (Poppi and McLennan 2010). Rainfall across the eight sites of the project (Figure 1b) is highly variable (McKeon 2006) with a mean annual rainfall range of 400mm to 800mm per annum. To date the sites have had below average annual rainfall and one exceptional monsoonal flood event both of which have affected results. Across all of these regions there is a dearth of well adapted introduced sown legumes (Gardiner 2016) hence the project has a focus on selecting, establishing and evaluating herbaceous pasture legumes adapted to these typically semiarid regions with neutral to alkaline cracking clay soils. A well-adapted legume in this environment would enhance: animal production (by increasing live weight gains, herd fertility and turnoff), the environment (by reducing enteric CH$_4$ emissions, sequestering carbon) (Coates et al., 1997; Eckard 2020; Suybeng et al., 2020). The legume genus *Desmanthus* is a herbaceous to suffruitcose member of the Mimosaceae family.
The genus has shown considerable potential for northern Australian regions (Cook et al., 1993; Hall 2005; Gardiner 2016) with recently some 50,000ha being sown commercially (Agrimix Pastures pers. com). The predominant cultivar is a blend known as Progardes® Desmanthus, a blend of selected and registered *D.bicornutus*, *D.leptophyllus* and *D.virgatus cultivars* (Gardiner 2016). This paper provides an overview of components of the project with a focus on Progardes® Desmanthus and cattle production in Queensland.

### Geographic spread of FEAST assessments

**Table 1.** Geographic spread of FEAST assessments, number of focus groups involved number farmers participating

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
<th>Number of focus groups</th>
<th>Total number of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Africa</td>
<td>Ethiopia</td>
<td>59</td>
<td>973</td>
</tr>
<tr>
<td></td>
<td>Kenya</td>
<td>19</td>
<td>570</td>
</tr>
<tr>
<td></td>
<td>Tanzania</td>
<td>15</td>
<td>251</td>
</tr>
<tr>
<td></td>
<td>Uganda</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>West Africa</td>
<td>Nigeria</td>
<td>9</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Ghana</td>
<td>6</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Mali</td>
<td>6</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Burkina Faso</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Niger</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>Malawi</td>
<td>6</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>Zimbabwe</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>South Asia</td>
<td>India</td>
<td>6</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>Nepal</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Bangladesh</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>149</strong></td>
</tr>
<tr>
<td><strong>Total number of farmers</strong></td>
<td></td>
<td></td>
<td><strong>2796</strong></td>
</tr>
</tbody>
</table>

Methods and Results

**Agronomic variety trials and broad acre plantings**

Between 2017 to 2020 a number of small plot legume variety trials and broad acre establishment trials were sown. The variety trials included some 60 accessions of mainly *Desmanthus* spp and other legumes. In these environments *Desmanthus* tends to be the main survivor with new *Desmanthus* accession (HG 170 & HG 171) performing as well as or better than existing cultivars when evaluated for establishment, persistence, and productivity. Progardes® establishment on a commercial scale was evaluated using broadacre farming techniques. Methodologies including; cultivation via adjustabar (light discs and air seeding Progardes); aerial herbicide application and aerial legume seeding; blade ploughing of Gidgee trees (*Acacia cambageae*) and aerial seeding. The adjustabar was only moderately successful at site 1, while establishment at sites 4 and 7 failed due to drought. The fixed wing aerial application of Glyphosate herbicide at 2-3 lt/ha to suppress grass growth onto either Mitchell and or Flinders grasses (*Astrebla* and *Isielema* spp.) at site 2 and at site 8 onto buffel grass has been successful with on average four *Desmanthus* plants establishing/m². At site 6, blade ploughing in 2017 followed by helicopter aerial seeding of Progardes® at 3 kg/ha has also been successful, although due to drought the initial establishment was slow but the Progardes® population has improved with each wet season.

**Paired paddocks, botanical composition and grazing**

Commercial sized paired grazing paddocks were established at sites 6 and 8, to compare animal performance on a grass only pasture (Control) with a grass plus Progardes® Desmanthus pasture (Legume). At both sites the botanical composition, by the BOTANAL (Tothill et al., 1992) methodology, was recorded before and after the first grazing period. At site 6 in 2019 the Progardes® composition was 8% with the remainder mainly being buffel grass, silk sorghum and Flinders grass. Due to COVID -19 no BOTANAL was recorded in 2020, but site 6 was grazed by 117 steers per paddock. After a short and below average rainfall wet season steers grazed the paddocks for 75 days. Steers grazing the Progardes® paddock gained 13kg/ head live weight more than the steers on the grass only control paddock. After a short and below average rainfall wet season steers grazed the paddocks for 75 days. Steers grazing the Progardes® paddock gained 13kg/ head live weight more than the steers on the grass only control paddock. In 2020, the botanical composition of the Progardes had improved and rainfall distribution may have favoured the Progardes® paddock (Cowan pers.com).
At site 8, a 147 day grazing study was conducted to investigate the effect of Desmanthus pasture on weight gain and carcass quality. The study commenced during the dry winter of 2019 when pastures were senescent, using four hundred tropical composite beef steers at 320 kg initial average live weight. Steers were randomly assigned to graze either Buffel grass only or mixed Buffel grass-Desmanthus pastures at 3.03 and 2.58 ha/steer stocking rate, respectively. Progardes® accounted for 12% botanical composition of the pastures. After grazing, steers were finished with high grain diet in a commercial feedlot for 123 days. No effect of pastures was observed on steer live weight and carcass quality; marbling, backfat thickness, hot carcass weight, dressing percentage and carcass grade. Although dry conditions prevailed throughout the grazing period, the control paddock was observed to receive more rain compared to the Desmanthus paddock. The rain led to new pasture growth that resulted in a 10% increase in the FNIRS estimated diet crude protein, which may have influenced live weight outcomes. FNIRS revealed no difference in the diet non-grass, which maybe be due to selective grazing of forbs and shrubs in the control paddock. These results indicate that a Desmanthus botanical composition of above 12% may be required for a difference in live weight and carcass quality to be observed. This is supported by modelling that suggests that pastures sown to Progardes® mostly act to prevent weight loss in the dry season rather than substantially increase rate of liveweight gain during the wet season when the grass only pastures are capable of supporting good rates of liveweight gain (Figure 2).

Figure 2: Modelled values for cumulative liveweight gain of Bos indicus (75%) early weaned steers to 26 months of age when consuming buffel grass pasture (grass only) or buffel grass sown with Progardes® comprising 20% of dry matter using values from the Nutrition EDGE manual (McLennan 2015). (Buffel grass: 9 to 10 MJ ME/kg DM, 8 to 10% CP/5 to 7% RDP; Desmanthus: 10 to 11 MJ ME/kg DM, 16% CP/10% RDP; wean November; join April; calve January)

Desmanthus - Antimethanogenic chamber studies

A study investigating the effect of supplementing beef cattle with incremental levels of Desmanthus leptophyllus cv. JCU1 and D. bicornutus cv. JCU4 on in vivo methane (CH₄) emissions and the role of tannins in rumen fermentation has been conducted at the CSIRO Lansdown Research Station. Fourteen yearling Droughtmaster steers were allocated to each of the two Desmanthus species and offered a basal diet of Rhodes grass (Chloris gayana) hay plus fresh Desmanthus at 0, 15, 22, and 31% of dry matter intake (DMI). The 15 and 31% Desmanthus periods lasted 21 days and the 22 and 0% Desmanthus periods, 14 days. Methane production was measured by open-circuit gas exchange in the last 2 days of each period. Results showed that irrespective of cultivar, incremental supplementation with up to 31% of Desmanthus led to a 10% linear decrease in CH₄ emissions and increase in DMI. The added tannin binder polyethylene glycol-4000 did not affect CH₄ yield but increased rumen NH₄-N and iso-acid concentrations. Therefore, on a low-quality diet, Desmanthus has the potential to increase intake and reduce CH₄ emissions. Even though its tannins can bind rumen proteins, the beef cattle antimethanogenic response to supplementation with Desmanthus may be a combination of rumen fermentation and tannin effects.

Steers and animal production (pen trial)

A group feeding pen study was carried out at Lansdown research station to study the effect of Desmanthus forage on beef cattle growth performance and carcass quality in an intensive feeding system. Forty-eight tropical steers with an initial live weight of 332 ± 22 kg were fed Rhodes grass hay basal diet and either 0, 15, 30 or 45% Desmanthus, consisting of equal proportions of three species (D. virgatus cv. JCU2, D. bicornutus cv. JCU4 and D. leptophyllus cv. JCU7). Lucerne hay was added to the diet to ensure that crude protein levels of the diets were similar to the 45% Desmanthus. The 0% Desmanthus steers were offered Rhodes grass and Lucerne only. The study took 124 days. At the end of the study steers were sorted into two groups based on live weight; the heavy steers were slaughtered in a commercial abattoir while the lighter steers were finished for 96 days using a high grain diet. Steers fed 15% Desmanthus were 20kg heavier than those fed 45%, but the other treatments were similar. A 13% linear decrease in feed intake with increase in Desmanthus level from 0 to 45% was observed, but it did not affect feed to gain ratio. No effect of treatment on live weight was observed after feedlot...
finishing. Carcass quality, hot carcass weight, back fat thickness and dressing percentage, from all treatments were similar. The results indicate that Desmanthus can produce carcass quality similar to the high-quality Lucerne forage for both forage and grain-finished tropical beef cattle.

**Soils and nutrient omission trials - Desmanthus growth**

A series of glasshouse trials was conducted to test the nutrient response of three Desmanthus genotypes in four alkaline rangeland soils. With no history of fertilisation, all soils were low in a number of nutrients, particularly P, S and Zn, limiting growth and quality of Desmanthus forage. In contrast to S or Zn deficiency, P deficiency severely decreased the capacity of Desmanthus to take up Mo and accumulate it in shoots, which may have negative implications on N\(_2\) fixation given a role of Mo in the process. The mechanism underpinning decreased Mo accumulation by P-deficient Desmanthus is being elucidated. Further research is needed to determine the optimal fertilisation treatments and to choose the most suitable Desmanthus genotype for specific soils.

**Discussion /Conclusions**

The practical implication of these finding are that Desmanthus: can be established on semi-arid Vertosol soils particularly when competition is reduced and rainfall is adequate; there are potentially new cultivars for these regions; has the potential to mitigate in vivo CH\(_4\) emissions by beef cattle in the drier parts of Northern Australia; is compatible with native and introduced grasses; can enhance beef production; P and certain trace elements may promote plant growth; thus is potentially good for beef production and the environment.

**Acknowledgements**

We acknowledge the Agrimix Pastures team, Prof. Rengel (UWA), Assoc. Prof Malau-Aduli (JCU), Project Partners and the valued funding from the CRC-P58599 and Meat & Livestock Australia Ltd P-PSH.1055.

**References**


Bee-friendly beef: developing biodiverse pastures to increase ecosystem services

Wagner, J.1; Ghajar, S.1, O’Rourke, M.2, Tracy, B.1

1School of Plant and Environmental Sciences, Virginia Tech, Blacksburg, VA., USA; 2USDA-NIFA, Kansas City, MO., USA

Key words: tall fescue, wildflowers, native grasses, bees, beef cattle

Abstract

The capacity of grasslands to provide ecosystem services, such as pollinator resources, is often limited by lack of plant biodiversity. This is true of grasslands in the eastern US that are dominated by tall fescue (*Festuca arundinacea*) a non-native, cool-season grass that is typically toxic to cattle. This paper summarizes a research project in Virginia, USA exploring the idea that ecosystem services provided by tall fescue-dominated grasslands can be improved by increasing the plant biodiversity available to beef cattle and bees. Within three 6.5 ha tall fescue grasslands, we established 0.8 ha plots with a 17 species mix of native warm-season grasses (NWSGs) and wildflowers. Beginning in 2018, we measured grass and wildflower establishment, attractiveness of wildflowers to bees, abundance and diversity of bee communities in biodiverse pastures and adjacent tall fescue pastures. Many of the 18 species sown established well except for NWSGs. Competition from wildflowers likely suppressed native grasses and limited forage availability for beef cattle. Cattle largely ignored the wildflowers. This finding suggests that cattle and pollinators can share this biodiverse grassland as their primary foods are mutually exclusive. The total number of bees was almost double in wildflower-enhanced grasslands compared with more typical tall fescue grasslands. We observed most bee landings on purple coneflower (*Echinacea purpurea*) and anise hyssop (*Agastache foeniculum*). Several weedy species such as milkweed (*Asclepias syriaca*) and musk thistle (*Carduus nutans*) were also attractive to bees. Preliminary analyses identified at least 28 bee morphospecies and a distinct bee community present in wildflower pastures. While these results were promising, more research is needed on ways to establish biodiverse grasslands so that a more optimal balance of grasses and wildflowers can be sustained to benefit both cattle production and pollinators.

Introduction

Native and managed bee populations have been declining around the globe (Potts *et al.*, 2016). Although multiple factors contribute to decline, habitat loss is likely the primary driver. Adding bee habitat to agricultural landscapes can bolster existing bee communities, increasing abundance and species richness (Paterson *et al.*, 2019). Pastures and rangeland, which covers 265 million hectares across the United States, could provide enough land area for large-scale wildflower plantings, while still providing forage for cattle (Baude *et al.*, 2016). A land-sharing approach provides an opportunity for agricultural production and conservation of biodiversity (Ekroos *et al.*, 2016) and could help mitigate bee decline (Kovacs-Hostyanszki *et al.*, 2017). A pasture designed for cattle production and bee conservation will mirror a grassland plant community, where grasses dominate but forbs fill other ecological niches. Native warm-season grasses (NWSGs) can provide valuable forage for cattle, especially during the summer months (Moore *et al.*, 2004, Tracy *et al.*, 2010, Backus *et al.*, 2017), and wildflowers will provide food and nesting resources for bees. If managed appropriately, NWSGs and native wildflowers should benefit bee populations and cattle. Little research exists about how using native grasses and wildflowers in pastures affects bee populations and cattle production, however. This project examined several aspects of NWSG-wildflower plantings and their use in pasture systems – namely plant community establishment, attractiveness of different wildflower species to bees, and overall bee abundance and diversity.

Materials and Methods

The experiment was conducted at the Virginia Tech Shenandoah Valley Agricultural Research and Extension Center (SVAREC) in Raphine, VA from 2018-2019. The study site was in central...
Virginia (37°55'56" N latitude, 79°12'51" W longitude, elevation: 530 m). The region has a humid continental climate, with an average monthly high temperature ranging from 7.9°C in January to 30.7°C in July. Pastureland was divided into nine 6.5 ha experimental units and assigned to three stocking treatments with three replications: 1) rotational stocking where cattle groups were moved through eight equal-sized (0.8-ha) paddocks, 2) the same rotational stocking scheme but with one paddock planted to a biodiverse NWSG + wildflower mixture, and 3) continuous stocking that represented a “business-as-usual” control treatment to reflect grazing practices in the eastern U.S. Establishment of the NWSG + wildflower paddocks was initiated during the fall of 2016 and eventually seeded with a mix of three NWSGs and 15 wildflower species at a rate of 13.5 kg/ha in early June 2017. The seed mix was 70:30 (by seed weight) of NWSGs: wildflowers. Percent cover of NWSG + wildflower species, weedy species, and bare ground was visually estimated in 0.25-m² square quadrats in 2018 and 2019 using a modified Daubenmire method (Daubenmire 1959). Bees were collected to assess abundance and diversity among bee communities.ollections began in June 2018 and 2019 and continued monthly until September. Two sets of traps were placed in each experimental unit consisting of one blue vane trap (SpringStar, Inc., Woodinville, WA, USA) and multi-coloured bee bowls. Bee observations were used to gather information on which flower species were the most attractive. Beginning in May 2018 and 2019, bee landings on all blooming flower species, including weedy species, in all treatments were observed. After assessing flowers blooming on a given day, six random patches of each blooming flower species were observed for one minute each. The size and bloom count of each patch were visually estimated and recorded.

### Results

**Native Grass/Wildflower Establishment**

Overall plant species composition changed substantially from 2018 to 2019. Average percent cover of bare ground was similar in 2018 (14%) and 2019 (15%) (Figure 1). The average cover of weedy species (species not sown as part of the NWSG + wildflower mix, such as thistle, white clover, fleabane, and cool-season grasses increased from 41% in 2018 to 63% in 2019. Coverage of all three NWSG species was minimal in both years. Black-eyed Susan was the dominant wildflower species in 2018, representing an average of 22% of total plant coverage. However, in 2019, it represented less than one percent of average percent cover. Lanceleaf coreopsis, perennial blueflax, and anise hyssop showed similar trends, all declining to less than one percent cover in 2019. In contrast, the coverage of grey-headed coneflower increased from 2018 to 2019. In 2018, grey-headed coneflower was on average 6% of the plant community and increased to 18% in 2019. Two annual species established early (annual gaillardia, partridge pea) but were not present by 2018.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously stocked</td>
<td>14.3[^a]</td>
<td>6.7[^a]</td>
<td>12.0[^b]</td>
<td>11.7[^a]</td>
<td>14.0[^b]</td>
<td>12.3[^b]</td>
<td>1</td>
</tr>
<tr>
<td>Rotationally stocked</td>
<td>4.7[^b]</td>
<td>6.3[^a]</td>
<td>13.3[^b]</td>
<td>14.3[^a]</td>
<td>6.3[^a]</td>
<td>13.0[^b]</td>
<td>2</td>
</tr>
<tr>
<td>NWSG + wildflower</td>
<td>8.7[^b]</td>
<td>3.7[^a]</td>
<td>23.3[^a]</td>
<td>19.0[^a]</td>
<td>24.0[^b]</td>
<td>20.5[^a]</td>
<td>3</td>
</tr>
</tbody>
</table>

In 2018, bee abundance showed a significant treatment by date interaction effect (P < 0.001), so sampling dates were analyzed separately. In July and August, the NWSG + wildflower treatment had significantly more bees present than the continuously and rotationally stocked treatments (Table 1). Bee abundance in 2019 differed by treatment (P = 0.02) and date (P < 0.001), although there was no significant interaction effect (P = 0.14). The NWSG + wildflower treatment again had more bees present in August. Although bees were numerically more abundant in the NWSG + wildflower treatment in July and September, the
means were not statistically different from the continuously and rotationally stocked treatments.

Table 2. Results of bee observations from 2018 and 2019. Values are means that represent proportion of observations when a bee was present on a bloom (± 1 SE). The planted and weedy species where a bee was observed the most frequently in both years are bolded.

<table>
<thead>
<tr>
<th>Flower Type</th>
<th>Observations</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anise hyssop</td>
<td>0.04 ± 0.07</td>
<td>0.42 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>Black-eyed susan</td>
<td>0.37 ± 0.09</td>
<td>0.44 ± 0.12</td>
<td></td>
</tr>
<tr>
<td>Grey-headed coneflower</td>
<td>0.33 ± 0.11</td>
<td>0.61 ± 0.12</td>
<td></td>
</tr>
<tr>
<td>Lanceleaf coreopsis</td>
<td>0.43 ± 0.11</td>
<td>0.33 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>Maximilian sunflower</td>
<td>0.43 ± 0.09</td>
<td>0.50 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>Oxeye daisy</td>
<td>0.25 ± 0.09</td>
<td>0.17 ± 0.11</td>
<td></td>
</tr>
<tr>
<td>Perennial sunflower</td>
<td>0.31 ± 0.08</td>
<td>0.17 ± 0.17</td>
<td></td>
</tr>
<tr>
<td>Purple coneflower</td>
<td>0.55 ± 0.09</td>
<td>0.42 ± 0.10</td>
<td></td>
</tr>
<tr>
<td>Buttercup</td>
<td>0.08 ± 0.04</td>
<td>0.08 ± 0.08</td>
<td></td>
</tr>
<tr>
<td>Chivebox</td>
<td>0.07 ± 0.21</td>
<td>0.17 ± 0.11</td>
<td></td>
</tr>
<tr>
<td>Flaxseed</td>
<td>0.18 ± 0.12</td>
<td>0.13 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Horseweed</td>
<td>0.17 ± 0.11</td>
<td>0.16 ± 0.11</td>
<td></td>
</tr>
<tr>
<td>Milkweed</td>
<td>0.83 ± 0.11</td>
<td>0.50 ± 0.22</td>
<td></td>
</tr>
<tr>
<td>Pokeweed</td>
<td>0.33 ± 0.14</td>
<td>0.67 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>Queen Anne’s lace</td>
<td>0.33 ± 0.21</td>
<td>0.22 ± 0.10</td>
<td></td>
</tr>
<tr>
<td>Thistle</td>
<td>0.56 ± 0.06</td>
<td>0.61 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>White clover</td>
<td>0.26 ± 0.06</td>
<td>0.19 ± 0.06</td>
<td></td>
</tr>
</tbody>
</table>

In the 2018 and 2019 growing seasons, 17 plant species, both sown and weedy, were observed for bee visitations. A total of 442 plants and 312 plants were observed to record bee visitations in 2018 and 2019, respectively. Among sown species, anise hyssop was visited the most frequently by bees in 2018, while grey-headed coneflower was visited the most often in 2019 (Table 2). Among weedy species, milkweed (Asclepias syriaca) and pokeweed (Phytolacca americana) attracted the most bees in 2018 and 2019, respectively. Bull thistle (Cirsium vulgare), anise hyssop, maximilian sunflower, and purple coneflower were consistently attractive to bees in both years.

Of the 38 bee species identified in 2018, 37 were native (data not shown). The only non-native species was the European honeybee (A. mellifera). Nineteen honeybees were collected, 14 of which were in the NWSG + wildflower treatment. There were no known honeybee hives within a 0.5 mile radius of the site, which could have influenced the number of honeybees observed. The NWSG + wildflower treatment had the most diverse community of bees, supporting 28 total species. Eight of those species were found only in that treatment: Bombus auricomus, Bombus griseocollis, Hylaeus affinis/modestus, Hylaeeus mesillae, LasioGLOSSum calidum, LasioGLOSSum leucozonium, LasioGLOSSum pruinosum, and Melissodes denticulatus.

Discussion [Conclusions/Implications]

Although NWSGs were planted as 70% of the seed mix, they composed less than 5% of the final plant community in both 2018 and 2019. During their first year of establishment, NWSGs invest in root growth rather than above-ground biomass (Keyser et al., 2011, 2012). They are easily outcompeted by other, faster growing grasses and broadleaf plants (Harper et al., 2007). Lack of establishment in the pastures was likely caused by competition from both the wildflowers included in the mix and weeds present in pasture seedbanks. Because the NWSGs in our experiment were planted simultaneously with wildflowers, and because they devote most of their resources to root system development, they may not have had enough time to develop adequate above-ground biomass to shade out competing wildflowers and weedy species.

Of the fifteen sown wildflower species, eight that established were attractive to bees. The bloom periods of the sown species were staggered over the course of the growing season so that floral resources were available from May through September, therefore maximizing bee conservation value (Tuell et al., 2008). Most of the wildflower species bloomed during June and July when other nectar and pollen resources were lacking (Koh et al., 2016). If designing a diverse wildflower mix to plant in pastures, we would recommend: lanceleaf coreopsis, perennial blueflax, oxeye daisy, anise hyssop, black-eyed Susan, purple coneflower, grey-headed coneflower, and maximilian sunflower. Several weedy species also attracted many bees. Thistle and milkweed were notably attractive to bees in both years. Thistles and milkweed emit fragrances attractive to pollinators (Theis et al., 2007) and produce high-protein pollen (Russo et al., 2019).

The NWSG + wildflower treatment attracted more bees compared with the other grazing treatments during July and August, especially. Pollinator abundance has been found to positively correlate with the number of wildflower blooms (Blaauw and Isaacs, 2014, Angelella et al., 2019), which could explain the higher bee abundances in the NWSG + wildflower treatment. Additionally, the mid- to late summer months are when pollinators traditionally experience a pollen dearth (Koh et al., 2016, Heller et al., 2019). The NWSG + wildflower pastures were blooming in midsummer and had pollen and nectar resources available, which may explain why more bees were present during those dates. This also may help explain why NWSG + wildflower treatment supported a greater diversity of bee species.

In summary, we found that planting a mix of NWSGs and wildflowers as pasture, can attract more bees and a greater diversity of bees than typical tall fescue-based pastures in this region. However, the diverse mix was not ideal if the
management goal seeks to improve summer forage availability for cattle along with resources for pollinators. Wildflowers established in much higher densities than expected and likely outcompeted the NWSGs. With few native grasses, the pastures were not viable for cattle production. Different planting methods, to be tested in future experiments, could increase the proportion of grasses present while still maintaining wildflowers, benefitting both cattle and bees. We also noted that thistles and milkweed were highly attractive to bees. While neither weedy species is usually desirable in a pasture, if a producer can maintain a manageable number of thistle and milkweed plants, bee populations in pasture systems could be enhanced with minimal changes to pasture management.

References


What are the main limits to smallholder livestock production in the tropics – according to farmers?

Duncan, A.J.1

1 International Livestock Research Institute, PO Box 5689, Addis Ababa, Ethiopia; Global Academy of Agriculture and Food Security, The Royal (Dick) School of Veterinary Studies and The Roslin Institute, University of Edinburgh, Easter Bush Campus, Midlothian EH25 9RG, UK;

Key words: livestock; feed; constraints; smallholder livestock production

Abstract
Livestock production is central to the livelihoods of a billion poor people. Transforming livestock production would have transformative effects on Sub-Saharan Africa and South Asia local economies. However, development efforts in the livestock sector have tended to be top-down without enough feedback loops to understand farmer realities and aspirations. This, despite the Farmer First movement that began in the 1990s. The Feed Assessment Tool (FEAST) was developed as a reaction to top-down livestock feed development approaches. FEAST facilitates a structured conversation with farming communities about their livestock production system and how it connects with the overall farming system. FEAST involves individual farmer interviews and focuses group discussions (FGD’s). The final element of each FGD is a conversation with farmers on problems and opportunities for their livestock enterprise. Farmers are asked to name the issues that most limit their livestock enterprise and rank them using a pair-wise ranking approach. The purpose of this exercise is to make sure that any following development activities consider the issues that really matter to farmers, whether they be feed issues or other issues. FEAST has been applied in over a dozen countries. The many published reports provide a global overview of the main issues facing poor livestock keepers seeking to enhance their livestock enterprise. This paper will provide a global overview of livestock constraints based on over 150 focus group discussions involving over one thousand farmers from various countries in SSA and South Asia.

Introduction
Livestock production is central to the livelihoods of over 1 billion poor livestock keepers in low-income countries. The mixed crop-livestock production systems account for the largest share of these poor livestock keepers. Households typically keep small numbers of animals to provide food for domestic consumption as well as manure and traction for arable production. There is considerable variation in how livestock are kept for commercial milk and meat consumption, but the trend is upwards as urban populations grow and incomes increase (Duncan et al., 2013). Satisfying the resulting growth in demand for milk and meat is an opportunity for smallholder farmers, but transitioning from subsistence to semi-commercial production is challenging. Yields of milk and meat are generally far below the animals biological potential, and development efforts to enhance productivity have often been disappointing. Productivity is influenced by a wide range of potential constraints, including the classic trio of feeding, genetics and health, and constraints related to basic husbandry knowledge, access to markets, lack of local infrastructure, access to finance, and a range of other factors.

Donors and governments look for promising intervention pathways and want to know where to invest their efforts and resources. This has spurred several initiatives to quantify the benefits of dealing with different constraints to help focus investment. For example, ILRI engaged in a priority setting exercise for livestock research by identifying a list of research themes and then scoring each using a composite index, e.g., benefit-cost ratios, pro-poor credentials, and environmental effects (Randolph et al., 2001). The World Bank commissioned some work to identify investment options for ruminant livestock feeding in developing countries (Thorpe et al., 2012). Similarly, the Bill and Melinda Gates Foundation funded the Livestock Knowledge Development Project (Staal et al., 2009) and, more recently, the Livegaps project (Mayberry et al., 2017), both aimed at using expert knowledge and modelling...
approaches to tease out the most efficient routes to improve livestock productivity in low-income countries. These efforts are welcome but tend to be data-driven without much consideration of the practical realities of smallholder farming practice. Farmers are excellent integrators of knowledge. Because their livelihoods depend on sound decision making, they are often best placed to offer insights into the most promising ways of improving the productivity of their livestock. However, there is a gap between conversations at the donor/government level and the realities facing farmers, and it is challenging to incorporate farmer perspectives into high-level decision making.

The Feed Assessment Tool (FEAST) was developed partly as a reaction to the lack of farmer involvement in the design of livestock feed intervention strategies. The tool is designed to guide a structured conversation between researchers/development agents and farmers to improve overall understanding of the local livestock production system and improve feeding issues. Although FEAST is designed as a community-led diagnosis of feed constraints leading to action on the ground, a by-product has been the collection of farmer perspectives on livestock feed constraints across many low and middle-income countries. In this paper, I present the results of 10 years of application of the FEAST tool across 14 countries to gain insights into the farmer perspective on livestock sector constraints.

Materials and Methods
The Feed Assessment Tool (FEAST) was originally developed around 2008 and has evolved since then (Duncan et al., 2012). The tool consists of a focus group discussion checklist, a household questionnaire and a data app that generates standard charts summarizing key elements of the livestock production system and the place of feed within that system. The tool is designed to be applied at the village/community level to support appropriate livestock feed options based on data and farmer perspectives. One important part of FEAST is the constraint ranking exercise. For this, focus groups discuss important local constraints to livestock production and, by consensus, come up with a list of the top five constraints. These may be related to any aspect of livestock production and not just feed issues. Once the shortlist of constraints is agreed the farmer group is asked to rank these using a pairwise ranking exercise. This eventually leads to a ranked list of constraints agreed upon by farmers.

I used the ranked lists of livestock production constraints as raw data for this analysis. Around 80 FEAST reports have been published, and these report findings from 149 focus groups conducted in 14 different countries in Sub-Saharan Africa and South Asia and involved 2796 farmers (Table 1). Each constraint description was scrutinized and allocated to one of nine constraint categories and within each category to a further series of “issues” within each category. For example, feed, health, and genetics were counted as broad constraint categories, but there were distinct issues within each. Thus, the feed constraint might be about feed shortage in general or seasonal feed shortage. The broad categories and sub-issues emerged through the analysis and were subjectively developed. Through this process, a total of around 700 “mentions” of specific issues were counted. These were weighted by their position in the ranked list to develop an importance score for each issue. The scores were allocated to ranks as follows: Rank 1 = 5, Rank 2 = 4, Rank 3 = 3, Rank 4 = 2, Rank 5 = 1).

Results
Results show that while the data presented is ad hoc and the coverage reflects the use of the FEAST tool; it provides a reasonably comprehensive overview of livestock development constraints from the farmer perspective across many countries, systems, and farmers. Feed shortage is often cited as the main constraint to improved livestock productivity (Ayantunde et al., 2005) without much evidence, but the current data bear this out. FEAST is, of course, focused on livestock feed, which may have skewed the responses somewhat. However, the question posed was general, and it was made clear that issues beyond feed should be considered. The “Big 3” constraints of feed, health and genetics all featured in the top five constraints mentioned by farmers as expected. The very high importance placed on water shortage as a key constraint to livestock productivity was less expected. “Water shortage” covered a range of issues from lack of ready access to drinking water, especially for dairy production, and lack of water for optimum growth of forage crops. Gaps in knowledge about basic livestock husbandry were also repeatedly mentioned by farmers, and this constraint ranked 4th on the list. This points to the need for a renewed focus on basic capacity building on livestock feeding, health and breeding at the farmer level – no small task, given the unfavourable ratios of farmers to extension workers. The data also highlight the importance of market quality and access to finance for smallholder farmers. In recent years, these issues have received increasing attention in development efforts by applying value chain approaches to livestock development. Still, this analysis
suggests that further attention to these issues is needed. The analysis has categorized constraints into a series of bins, but this does not suggest a piecemeal approach to livestock development efforts. Suppose we have learnt anything in the last ten years. In that case, it is that dealing with feed, breed, health and market constraints in isolation is futile and that what is needed is to work with bundled intervention packages that address several issues simultaneously. Major constraint categories identified in this study were feeding, health and ‘infrastructure.’ The infrastructure category was dominated by the issue of water shortage and included poor livestock housing, lack of machinery and poor road infrastructure.

Knowledge constraints also figured strongly in farmer responses, and constraints related to breed quality ranked 5th among constraint categories. Input/output markets and constraints related to finance ranked 6th and 7th on the list. Drilling down to the specific issues within these broad categories shows a similar pattern (Figure 2). A general feed shortage was the most-mentioned livestock constraint, followed by livestock disease/pests. Knowledge on livestock husbandry and water shortage featured strongly, as did breed quality and access to cash/credit. Intermediate importance was placed on quality and access to veterinary services, access to markets, grazing land issues, seasonal feed shortage, low prices for livestock products and markets for livestock. Concentrate feed issues, lack of forage seeds, and housing was also of intermediate importance in farmers’ responses. A range of minor issues was also identified, as shown in Figure 2.

Table 1: Geographic spread of FEAST assessments, number of focus groups involved, number farmers participating.

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
<th>Number of focus groups</th>
<th>Total number of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Africa</td>
<td>Ethiopia</td>
<td>59</td>
<td>973</td>
</tr>
<tr>
<td></td>
<td>Kenya</td>
<td>19</td>
<td>570</td>
</tr>
<tr>
<td></td>
<td>Tanzania</td>
<td>15</td>
<td>251</td>
</tr>
<tr>
<td></td>
<td>Uganda</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>West Africa</td>
<td>Nigeria</td>
<td>9</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Ghana</td>
<td>6</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Malawi</td>
<td>6</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Burkina Faso</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Niger</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>Malawi</td>
<td>6</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>Zimbabwe</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>South Asia</td>
<td>India</td>
<td>6</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>Nepal</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Bangladesh</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>149</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2796</td>
</tr>
</tbody>
</table>

**Figure 1:** Number of mentions of key constraints to livestock productivity across 149 focus discussions group involving 2796 farmers in 14 countries.

**Figure 2:** Tree map showing the relative importance of a range of livestock constraints according to farmers.
Discussion
While the data presented is ad hoc and the coverage reflects the use of the FEAST tool, it provides a reasonably comprehensive overview of livestock development constraints from the farmer perspective across many countries, systems, and farmers. Feed shortage is often cited as the main constraint to improved livestock productivity (Ayantunde et al., 2005) without much evidence, but the current data bear this out. FEAST is, of course, focused on livestock feed, which may have skewed the responses somewhat. However, the question posed was general, and it was made clear that issues beyond feed should be considered. The “Big 3” constraints of feed, health and genetics all featured in the top five constraints mentioned by farmers as expected. The very high importance placed on water shortage as a key constraint to livestock productivity was less expected. “Water shortage” covered a range of issues from lack of ready access to drinking water, especially for dairy production, and lack of water for optimum growth of forage crops. Gaps in knowledge about basic livestock husbandry were also repeatedly mentioned by farmers, and this constraint ranked 4th on the list. This points to the need for a renewed focus on basic capacity building on livestock feeding, health and breeding at the farmer level – no small task, given the unfavourable ratios of farmers to extension workers. The data also highlight the importance of market quality and access to finance for smallholder farmers. In recent years, these issues have received increasing attention in development efforts by applying value chain approaches to livestock development. Still, this analysis suggests that further attention to these issues is needed. The analysis has categorized constraints into a series of bins, but this does not suggest a piecemeal approach to livestock development efforts. If we have learned anything in the last ten years, dealing with feed, breed, health and market constraints in isolation. What is needed is to work with bundled intervention packages that address several issues simultaneously.

Acknowledgements
FEAST was originally developed as part of the Forage Adoption Project funded by the International Fund for Agricultural Development (IFAD). This analysis was supported by the CGIAR Research Programme on Livestock.

References


THEME 4: WILDLIFE AND MULTI-FACETS OF RANGELAND/GRASSLAND

Topic: Biodiversity, Ecosystem Services and Ranching
Brazilian Pampa rangelands: challenges in the face of soybean expansion

Moreira, J.G.; Maciel, R.G.; Waquil, P.D.; Tourrand, J. F.

1 UFRGS-PGDR, Porto Alegre-RS, Brazil;
2 UFRGS-PGDR, Porto Alegre-RS, Brazil;
3 CIRAD-GREEN, Univ. Montpellier, MAAF, Montpellier, France / UFSM-PPGZ, Santa Maria-RS, Brazil

Key words: pampa; paradox; Soybean crops; ranchers

Abstract
The Pampa biome extends throughout the Uruguayan territory, part of Brazil, Argentina and Paraguay. It is characterized by being a natural pastoral ecosystem, in which livestock represents the best option for sustainable use for food production purposes, and favors the conservation of its rangelands. In addition to contributing to the conservation of natural pastures, it was along with livestock activities that the gaucho’s way of life was developed. However, the cultivation of soybeans and eucalyptus plantations in the Pampa in all its extension is the localized version of the global dynamics of valuing the production of agricultural commodities affecting various socio-ecosystems of natural fields around the world. In Brazil, the Pampa is present only in the southern half of the state of Rio Grande do Sul, and is the second most devastated biome in the country. Between 2000 and 2019 there is a dizzying growth in the areas cultivated with soy in the Pampa, with an increase of 24% of the areas cultivated with soy. During the same period, natural fields also decreased by 24%. The expansion of areas cultivated with soybeans is mainly due to the high price of commodities, the availability of land for rent in the region, the strong incentive on the part of the Brazilian State to produce commodities for export and the regularization of genetically modified seeds. Thus, extensive livestock farming considered economically unattractive when compared to more intensive production systems and the lack of incentives for producers to maintain natural fields sometimes imposes difficulties to maintain rangelands. In view of this scenario, the objective of this work is to identify how the advance of soy in the Brazilian Pampa can represent an obstacle to the maintenance of natural fields as a base for livestock.

Introduction
The way in which Brazilian meat is produced has been strongly questioned in recent years, especially meat from animals raised in the Amazon region where deforestation rates increased considerably in 2020, including imposing barriers to the exportation of Brazilian meat produced in areas of illegal deforestation, especially after Rajão et al. (2020) identified that at least one in eight of the 4.1 million head of cattle traded in slaughterhouses each year comes directly from properties that may have been deforested, which represents 2% of the meat produced in the Amazon and 13 % of Cerrado production.

However, it is important to note that Brazil has five more biomes in addition to the Amazon, namely: Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal, each with different types of vegetation and fauna (Brazil 2015), making any generalization dangerous or simplification in the face of so much diversity.

In the Pantanal biome, for example, sustainable cattle ranching, in addition to adapting to the conditions of the Pantanal biome, guarantees the livelihood and social reproduction of Pantanal cattle ranchers and is capable of meeting the demand for healthy and sustainable animal products (Araujo et al., 2018). The Caatinga is considered one of the most traditional sheep and goat breeding regions, and this is an activity of great economic and social importance for the region, where 91.6% of the population goats are found in Brazil and 57.5% of the number of sheep (Neto 2016).

In the case of the Pampa biome, which represents only 2% of the Brazilian territory, and 63% of the state of Rio Grande do Sul, beef cattle was the first and most fruitful economic activity adapted to the natural pastures of this biome, becoming a basic
component of the gaucho identity and inseparable element of the landscape of this territory (Litre 2010). With degradation levels higher than the Cerrado and the Amazon, with less than half of the native vegetation preserved, the Pampa was only recognized as a biome in 2004 and is the least protected biome in Brazil, even though there are approximately 3000 species of plants in the Pampa biome, with more than 450 varieties of grasses, in addition to about 500 species of birds and 100 of terrestrial mammals (Brazil 2015; Fontana and Reed 2019). Natural grassland is one of the main natural resources of this biome that can also be characterized as a rangeland, defined as “the land where the potential native vegetation is predominantly grasses, grassy plants, herbaceous plants or shrubs” (Kauffman and Pyke 2001).

Nabinger et al., (2005) affirm that the natural pasture resource represents a unique source of forage genetic material, still little studied regarding its different aptitudes to form cultivated pastures or even for other uses such as landscaping, leisure, etc. and be an incomparable substrate for adding value to products from domestic ruminants, it is no longer enough to produce at any price, but it must be produced in an ecologically acceptable environment and with measurable socioeconomic reflexes. However, in the year 2000, as natural pastures represent 85% of the vegetation of the Brazilian Pampa, and in 29 that number dropped to 61%. During the same period, the crop that expanded the most in terms of area was soybean crops, going from an area of 14% to 38% (Mapbiomas 2020; IBGE / PPM, 2020).

For many producers, soy represented a great economic strategy and to maintain livestock activity, however, less capitalized ranchers or those who prefer to maintain their natural fields are experiencing difficulties in resisting the economic, social and environmental pressures exerted by the soy production dynamics. Thus, the objective of this work is to identify how the advance of soy in the Brazilian Pampa can represent an obstacle to the maintenance of natural fields as a base for livestock.

Methods and Study Site

This research is characterized as quantitative and qualitative, considering that it gathered mathematical data to describe the evolution of livestock production and soy cultivation in Rio Grande do Sul. According to (Gerhardt et al., 2009) the combined use of qualitative and quantitative research allows to collect more information than could be achieved in isolation. The main instrument for collecting qualitative data was the semi-structured face-to-face interview. According to (Gerhardt et al., 2009) the interview is an alternative technique of collecting undocumented data on a given topic, a technique of social interaction used to collect essentially subjective data, which are related to values, attitudes and opinions of the interviewed subjects.

The municipality chosen for the study was Dom Pedrito, located in the Brazilian Pampa, in which soy production dynamics is more consolidated. In 2000, soybeans occupied only 4,000 hectares of the municipality’s agricultural area, and in 2019, that number increased to 110,000 occupied by the cultivation of the grain. As soybeans gain space, the number of hectares occupied by natural pastures has dropped from 320,000 in 2000 to 240,000 in 2019 (Mapbiomas 2020). During the same period (2000-2019), the cattle herd in the municipality of Dom Pedrito decreased by 25%. The reduction in the rangelands areas and the decrease in the number of cattle can be an indication of intensification or even replacement of livestock activity by cultivation of crops, considering that in the previous decade (1990-2000) the number of cattle increased by 4% at the end of that period (IBGE / PPM 2020).

In order to identify the challenges for the maintenance of the natural fields of the Brazilian Pampa in the opinion of the ranchers, 14 interviews were conducted with ranchers in the municipality of Dom Pedrito-RS, with the support of EMATER / ASCAR-RS1 and the Farmers Association, in the year 2018. Some interviews is part of the data collection for the Global-Rural2 - Rural Change and Development in Globalization project coordinated by the Department of Geography and Earth Sciences at Aberystwyth University (UK). The data analysis technique was Content Analysis, considered by (Bardin 2002) to be suitable for studies that seek to understand the opinion of individuals on a given topic.

Results

According to Otte et al., (2017, p. 1) “livestock production has significantly changed over the past decades with industrial systems and their associated value chains being dominant in developed countries and becoming increasingly important in developing countries where traditional livestock production still provides an important source of income for a large share of the population”. In general, the authors point out as the main characteristics of industrialized

1Association of Technical Assistance and Rural Extension Enterprises / Southern Credit and Rural Assistance Association of the State of Rio Grande do Sul
2 More information https://globalruralproject.wordpress.com/
systems of rearing, the large number of animals of similar genotype being reared, predominantly in confinement, with high rates of turnover of the animal population in a single location with major transformations in the global production of feed for animals, one of the main ones is the replacement of fodder by industrialized feeds dense in nutrients (Otte et al., 2007).

Unlike industrial production systems, animal husbandry based on the natural pastures of the Rangelands systems, in addition to being the oldest, is considered the most appropriate strategy for promoting human well-being, as it provides means of adequate livelihoods, offer important ecosystem services, promote wildlife conservation and maintain traditions and cultural values in these territories (Blench 2001; Dong et al., 2016; Coppock et al., 2017), as is the case with traditional productive systems of the Brazilian Pampa.

However, soy advances over the Pampa natural pasture areas, increasing the challenges for the maintenance of natural fields as a basis for livestock farming in the Brazilian Pampa. During the interviews carried out with small, medium and large producers in the city of Dom Pedrito, some reports stand out and illustrate the view of producers about these challenges imposed on them in the face of this advance.

Unlike industrial production systems, animal husbandry based on the natural pastures of the Rangelands systems, in addition to being the oldest, is considered the most appropriate strategy for maintaining human well-being, as it provides means of adequate livelihoods, offer important ecosystem services, promote wildlife conservation and maintain traditions and cultural values in these territories (Blench 2001; Dong et al., 2016; Coppock et al., 2017), as is the case with the Brazilian Pampa.

However, as previously discussed, soy advances over the natural pasture areas of the Pampa, increasing the challenges for the maintenance of natural fields as a basis for livestock farming in the Brazilian Pampa. During the interviews carried out with small, medium and large producers in the city of Dom Pedrito, some reports stand out and illustrate the view of producers about these challenges imposed on them in the face of this advance.

According to (Moreira et al., 2019), one of the main factors for the expansion of soy in the Brazilian Pampa is the economic factor, considering the rapid financial return generated by crops, either by leasing the areas for or producing the grain itself. Making this relationship of economic return between livestock, soy and livestock based on natural fields, one of the producers interviewed in our survey claims to be concerned with the destruction of the fields and states that: “... very good fields are being destroyed by man that way without concern, and it is not for lack of technique, we are full of techniques. Improving the native field with implantation of winter pastures, making a summer pasture, it is possible to earn much more than soybeans, sheep and cattle earn from soybeans in terms of economic return”.

In this sense, results of several experiments with native fields, show a significant increase in the productivity of cattle only with the intensification of the use of process technologies (which do not involve the use of inputs), going from 60 kg of live weight per hectare year to about 230 kg live weight per hectare year, and which can reach 900 kg live weight per hectare year in the case of implementation of species, such as winter forage, for example (Nabinger and Jacques 2017) corroborating the producer’s speech. In other words, the challenge identified here is to find ways to pass on management techniques to viable and achievable producers in the short, medium and long term so that extensive livestock farming becomes competitive against soy.

Another challenge posed by soybeans is to regain autonomy after leasing the areas for growing the grain. One of the producers argues that: “When it is decided to let soy enter the property, and the cattle are removed, the cattle are not always acquired again, and there is no longer that exceptional field. Surely you will be swallowed by the soybean planter, this is a natural thing in this culture”. Another producer explains that: “The cultivation of soybeans requires cultivated pasture. As you will not have the return of the native field, then you need capital to implement the pasture later”.

Corroborating with the speech of cattle ranchers, (Moreira et al., 2019) identified as a consequence of these reconfigurations the reduction of areas destined to livestock on natural pastures, the suppression of the biome and loss of biodiversity, factors that are potentially capable of generating replacement of livestock activity based on fields by livestock dependent on cultivated pastures. There is also a pressure from the political-institutional sphere for modernization of livestock activity, using more and more agricultural pastures among other “modernizing” factors (Severo and Matte 2020).

The section in which the producer states that it is possible to be “swallowed by the soybean planter”

3 Native field is the same as natural pasture
draws attention, which may indicate reflexes in the socio-cultural dimension of the Brazilian Pampa, with the reduction of traditional livestock in an extensive way (Severo and Matte 2020).

**Discussion/Conclusions/Implications**

The speeches of cattle breeders reveal a paradox. On the one hand, the cultivation of soy destroys natural fields, raises the price of land, changes the landscape and changes the habits of producers. On the other hand, it diversifies production, generates more income, creates marketing and fodder alternatives for cattle. Those who feel this dilemma most are the less capitalized ranchers or who prefer to maintain their natural fields, and find it difficult to resist the economic, social and environmental pressures exerted by the soy production dynamics in the Pampa.

Thus, the main obstacles identified to maintain natural fields as the basis for livestock breeding were: the difficulty of implementing rangelands management techniques to gain greater productivity; not to become a “hostage” to cultivated pastures and; resist the pressure exerted by the financial return of the lease of land for the cultivation of soy, or the cultivation of the grain by the producer himself.

In order to contribute to the conservationist practices of producers being valued, we suggest more holistic approaches that can measure the economic, social and cultural value of the natural fields of the Brazilian Pampa. Therefore, as perspectives for future research, it is recommended, for example, a One Health approach, which is capable of studying the human-animal-environment interconnections, and on the effects of livestock activity on human, animal and natural field health, interconnections intensified over four centuries in the Brazilian Pampa.

**References**


Brazilian Institute of Geography and Statistics / Municipal livestock research - IBGE / PPM. Number of herds by type of herd. Available at: <https://sidra.ibge.gov.br/tabela/3939>.


Fontana, V. and Reed, S. *More degraded than Cerrado and Amazon, Pampa is the least protected biome in the country.* Available at: <https://www.nationalgeographicbrasil.com/meio-ambiente/2019/10/degradacao-cerrado-amazonia-pampa-bioma-brasil-rio-grande-do-sul-vegetacao>.


The new tendencies of environmental impact assessment of livestock production: a road testing of LEAP/FAO Biodiversity Assessment Guidelines in pastoral systems in Uruguay

de Santiago, F.¹, Pompozzi, G.²,³, Simó, M.², Blumetto, O.¹


Key words: species richness; diversity; ecosystem integrity index; natural grasslands

Abstract

After the publication of the “long shadow of cattle” report, ruminant production systems have received great pressure for their contributions in greenhouse gases (GHG). However, the environmental effects of human activities are much broader than GHG production and in some cases, there are positive contributions. In order to broaden the environmental perspective and with the encouragement of governments, the private sector and NGOs, LEAP-FAO has developed environmental assessment guidelines for the world’s livestock production systems. This paper presents a road-testing of the Biodiversity Assessment Guideline at farm scale for six case studies in pastoral livestock systems in Uruguay. The producers involved correspond to farmers with a mixed livestock system (cows and sheep) with a full cycle and areas ranging between 2000 and 5000 hectares. Three of the farms have production based 100% on natural grasslands, while the other three had 30% of their area with sown pastures. The application of the guide at local level implies the use of the system of pressure, state and response indicators (PSR). The recommendation of the guide in its public review version requires a minimum set of 24 indicators, which can also be divided into several measurable variables. The results obtained in this study showed that the complete set is a reliable tool to evaluate the functioning of the systems in terms of their contribution to biodiversity conservation. However, some are more sensitive than others to evaluate changes depending on the scale. For example, the change in land use due to planting of forage crops clearly affects birds and arthropods such as spiders; though, due to scale of habitat use is less clear the global effect in bird population. The state indicators related to richness and diversity of species from different taxonomic groups is very relevant but result the more expensive issue in the assessment. Global indicators as the Ecosystem Integrity Index (EII) show a consistent effect of intensification but the connectivity in the actual percentages of natural grassland substitution is still good.

Introduction

After the publication of the “long shadow of cattle” report, ruminant production systems have received great pressure for their contributions in greenhouse gases (GHG). However, the environmental effects of human activities are much broader than GHG production and in some cases, there are positive contributions. In order to broaden the environmental perspective and with the encouragement of governments, the private sector and NGOs, LEAP-FAO has developed environmental assessment guidelines for the world’s livestock production systems. This study presents a road-testing of the Biodiversity Assessment Guideline at farm scale for six case studies in pastoral livestock systems in Uruguay.

Materials and Methods

The application of the LEAP guidelines at local level implies the use of the system of pressure, state and response indicators (PSR). The recommendation of the guide in its public review version requires a minimum set of 24 indicators, which also can be divided into several measurable variables. For doing the road-testing at farm level in Uruguay, six study cases were involved. These study cases correspond to farmers with a mixed livestock system (cows and sheep) with a full cycle and areas ranging between 2000 and 5000 hectares. Three of the farms had 100% production based on rangeland (natural grasslands with different proportion of shrubs, isolated trees and small groups of trees) while the other three had 30% of their area with sown pastures. The table 1
resumes the set of indicators evaluated, the variables recorded, and the methodology used.

**Table 1:** Set of basic indicators recommended by guidelines, variables recorded, and methodology used in this study

<table>
<thead>
<tr>
<th>Thematic issues</th>
<th>Category</th>
<th>Variables recorded</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedural checks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A scoping analysis was conducted</td>
<td>R</td>
<td>Scope of study is decided</td>
<td>Analysis of limits of the system studied</td>
</tr>
<tr>
<td>Regulatory constraints and extrinsic value are considered.</td>
<td>R</td>
<td>IUCN red listed species and national regulations such as protected areas and species</td>
<td>Consultation of national and international regulation</td>
</tr>
<tr>
<td>Progress is monitored</td>
<td>R</td>
<td>Measures are repeated every certain time</td>
<td>Compare results every time</td>
</tr>
<tr>
<td>Stakeholder engagement</td>
<td>R</td>
<td>Perspective/stakeholder analysis</td>
<td>Stakeholders inquiry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iterative stakeholder engagement</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat protection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildlife habitats under the farm influence are inventoried (mapped) and protected</td>
<td>R</td>
<td>Different habitats are inventoried and mapped</td>
<td>Satellite images analysis and field validation</td>
</tr>
<tr>
<td>Semi-natural habitats in the landscape</td>
<td>P</td>
<td>Area or proportion (relative to the area controlled by the user)</td>
<td>Mapping</td>
</tr>
<tr>
<td>Grassland restoration</td>
<td>R</td>
<td>Area of degraded grassland restored through improved grazing management</td>
<td>Inventory of restoration initiatives</td>
</tr>
<tr>
<td>Habitat change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil erosion and soil erosion risk are mapped and a management plan is implemented</td>
<td>R</td>
<td>Soil erosion and soil erosion risk are mapped and a management plan is implemented</td>
<td>Evaluated through EII (Blumetto et al., 2019)</td>
</tr>
<tr>
<td>Degraded soil</td>
<td>P</td>
<td>Area or proportion (relative to the area controlled by the user) of degraded soil</td>
<td>Evaluated through EII (Blumetto et al., 2019)</td>
</tr>
<tr>
<td>Livestock density</td>
<td>P</td>
<td>Livestock density in number of animals or other livestock units</td>
<td>Stock registration of farmers</td>
</tr>
<tr>
<td>Habitat conversion</td>
<td>P</td>
<td>Area or rate of conversion of natural and semi-natural habitats</td>
<td>Mapping of environments and lands uses</td>
</tr>
<tr>
<td>Wildlife conservation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Priority actions promoting species with high conservation value are listed and implemented</td>
<td>R</td>
<td>High conservation value includes national and international designations</td>
<td>Actions in management if exist</td>
</tr>
<tr>
<td>Particular species (with high conservation value)</td>
<td>S</td>
<td>Presence of priority conservation species</td>
<td>Species in Uruguayan priority conservation lists</td>
</tr>
<tr>
<td>Thematic issues</td>
<td>Category</td>
<td>Variables recorded</td>
<td>Methodology</td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Species richness or diversity</td>
<td>S</td>
<td>Number of species (S) and Shannon diversity index (H) of herbaceous plants, trees, birds and spiders</td>
<td>Botanic census, MacKinnon lists, pitfall traps and grasses and bushes aspirations</td>
</tr>
<tr>
<td>Invasive exotic species</td>
<td>R</td>
<td>Existence of control</td>
<td>Farmer’s control plan</td>
</tr>
<tr>
<td>Invasive exotic species</td>
<td>P</td>
<td>Presence/absence, abundance and/or distribution</td>
<td>Registration of alien plants and animals</td>
</tr>
<tr>
<td>Pollution &amp; aquatic biodiversity</td>
<td>R</td>
<td>Pesticides, veterinary products application</td>
<td>Records of farmers</td>
</tr>
<tr>
<td>A management plan is in place for the application of ecotoxic agrochemicals</td>
<td>R</td>
<td>Fertilizer application</td>
<td>Records of farmers</td>
</tr>
<tr>
<td>A nutrient management plan is in place to rationalize fertilizer application</td>
<td>R</td>
<td>Length or proportion (relative to length controlled by the user, or to the length in need of protection)</td>
<td>Mapping</td>
</tr>
<tr>
<td>Protected waterways</td>
<td>R</td>
<td>Length or proportion (relative to length controlled by the user, or to the length in need of protection)</td>
<td>Mapping</td>
</tr>
<tr>
<td>Biological indicators of water quality</td>
<td>S</td>
<td>Fish richness and diversity</td>
<td>Electro-fishing in two reference streams</td>
</tr>
<tr>
<td>Off-farm feed</td>
<td>R</td>
<td>Categorizing and countifying off farm feed</td>
<td>Food purchase record</td>
</tr>
<tr>
<td>An inventory of the off-farm feed being used is established</td>
<td>R</td>
<td>Tracking of off farm feed</td>
<td>Investigating feedstuff supply chain</td>
</tr>
<tr>
<td>Traceability systems for feedstuff is implemented</td>
<td>R</td>
<td>Tracking of off farm feed</td>
<td>Investigating feedstuff supply chain</td>
</tr>
<tr>
<td>Share of imported feed</td>
<td>P</td>
<td>Share of imported feed from areas that are certified/ deforested/ of high conservation value</td>
<td>Registering origin of imported feed if correspond</td>
</tr>
<tr>
<td>Landscape scale conservation</td>
<td>R</td>
<td>Habitat mapping and assessment of connection between habitat patches and between water bodies</td>
<td>Assessment of measures adopted if necessary</td>
</tr>
</tbody>
</table>

**Results**

The study has two main groups of results, the own biodiversity indicators results and the analysis of the applicability of guidelines, on which we will focus the discussion.

**Indicators results (selection)**

The application of ecosystem integrity index (EII) gives a general view of ecosystem state and show global values ranging from 3.1 to 4.0 as displayed in figure 1. There are variations between paddocks within each farm, and is a beat lower in farms with 30% of pastures (B, E and F). Nevertheless, the connectivity of different ecosystems is still good for all the farms.
Regarding to wildlife communities, 196 species of birds were recorded considering all farms, 26 of these species are included in priority conservation list (Soutullo et al, 2013). We recorded 162 species for natural grasslands, 89 species in sown pastures and 90 species in natural forests, 16 of which are exclusive from this environment.

Spiders were represented by 79 species in all farms, and two of them are considered of conservation priority according to the Uruguayan priority species list for spider conservation importance (Ghione et al., 2017). The species richness and diversity of spiders was clearly higher in natural grasslands (S: 74; H’ diversity index: 2.97) comparing to sown pastures (S: 45; H’ diversity index: 2.75).

A total of 35 species of fish were collected, with 20 species in the most diverse stream and 4 species in the least diverse. Ten of the recorded species are considered priority for conservation (Soutullo et al., 2013)

**Analysis of Guidelines applicability**

The application of the different indicators had three main sources of information: (1) satellite images and pre-existing mapping, (2) productive records of the farmers and (3) field work to survey the different wildlife groups. The information required was adequately available and had high quality levels. The evaluation of state indicators required a significant investment of time of several specialists and varied operational resources (as travelling costs and laboratory analysis).

**Discussion and Implications**

This work is the first road testing of this guide in local level analysis (farm or landscape). The set of recommended indicators published in the public review version, was applied without technical problems. Both general information and farmer individual data were adequately accessible and then, the obtention of pressure or response indicators was completely possible. However, these indicators have relative low value if we do not have adequate state indicators to measure the consequences of management measures taken (response) or land uses and management of productive systems (pressures). The state indicators are only three: species richness or diversity, particular species (with high conservation value) and biological indicators of water quality (see table1). These indicators have really a wide spectrum of possibilities related to variables or taxonomic groups to study, but then, their value depends strongly on how comprehensive the study is done. In our case the inclusion of flora (herbaceous and woody), birds, fishes and spiders, bring a wide panorama including plants, vertebrates and invertebrates. However,
these kinds of studies are very expensive, in time and money, to carry out. In addition, each group requires a certain number of specialists. Some can be recorded in a single time, but most of them need more instances, often seasonal assessments. The EII is a more economic tool for a state indicator at ecosystem level, including the possibility of adapting life cycle thinking by application in off farm feed production. Nevertheless, persist the necessity of obtaining some information at species or community level.

Finally, we consider that the LEAP’s biodiversity assessment guidelines is a useful tool for evaluate the interaction of productive system with the environment and planning management in consequence. It is necessary to find the adequate amount of resources for make the studies such comprehensive and deep as possible. In studied cases, a high richness and diversity have been recorded in these systems, which demonstrate the importance of it for maintaining habitat for wildlife species. The results obtained in communities such as birds or spiders also showed that substitution of natural grasslands by pastures could reduce species richness and diversity, so this way of production intensification has to be carefully studied for not to compromise the sustainability of the ecosystems involved.

Acknowledgements
We want to thank to Uruguayan CREA Federation, and all the farmers and their families involved in this project. We also appreciate the financial support of the National Meat Institute (INAC) and the National Agency of Research and Innovation (ANII).

References


Comparing empirical with perceived trends in wildlife, livestock, human population and settlement numbers in pastoral systems: The Greater Maasai Mara Ecosystem, Kenya

Juliet B. Kariuki, Joseph O. Ogutu, Shem C. Kifugo, Jully S. Senteu, Gordon Ojwang, Han Olff

University of Hohenheim
International Livestock Research Institute
Kenya Wildlife Trust
Directorate of Resource Surveys and Remote Sensing of Kenya
University of Groningen

Key words: wildlife, livestock, populations, Maasai Mara Ecosystem

Abstract

Human activities are driving wildlife population declines worldwide. However, empirical understandings of their operation and consequences for wildlife populations and habitats are limited. We explored relationships between empirical and perceived wildlife and livestock population trends in Kenya using data on i) aerial monitoring of wildlife and livestock populations during 1977-2018, ii) human population censuses; and iii) semi-structured interviews with 338 male and female respondents from 250 households from four zones of the Greater Maasai Mara Ecosystem in 2019 and 2020. Wildlife numbers declined by 72.3% but sheep and goats increased by 306.4%. Yet nearly 50% of the interviewees perceived increases in wildlife numbers during 2011-2020 but concurrent decreases in livestock numbers because wildlife compete with livestock for resources. About one third of the respondents perceived an increase in the number of people living within conservancies and around the reserve and considered this indicative of a developing and thriving community. Notable discrepancies between the empirical and perceived trends were often more apparent than real and collectively suggest that incentives that promote wildlife are evidently viewed as less attractive than those that encourage increasing human and livestock numbers. Reconciling such apparent contradictions in empirical and perceived patterns is essential to extracting insights for formulating policies for sustaining livestock and wildlife populations and their habitats while promoting human welfare in grasslands.

Introduction

Grasslands host rich biodiversity and support agricultural production through livestock grazing on forage that cannot be used directly by humans. Despite the wealth of benefits offered by grasslands, human activities are driving wildlife population declines in Africa (Ogutu et al, 2011; 2014; Holechek and Valdez, 2018; Jones et al, 2018). Declines in Kenya are caused by the degradation of grasslands by anthropogenic land use change and amplified by climate change and widening variability. These processes jointly put enormous pressures on pastoralism, sedentary livestock ranching and wildlife conservation in Kenya’s rangelands, including inside protected areas (Ogutu et al, 2016, 2014).

While substantial investments have been made in monitoring wildlife and livestock numbers in Kenya’s rangelands, far less has been invested in the analysis and interpretation of animal population trends that incorporate perspectives of resident communities (Ogutu et al, 2016). Combining statistical trend analyses with analyses of perceptions of local inhabitants is important to enhance the formulation and implementation of appropriate policies. Here, we combine statistical analysis of wildlife and livestock population trends based on aerial survey monitoring data with analysis of community perceptions derived from interviews conducted in the Greater Maasai Mara Ecosystem (GMME). We explore the extent to which local views corroborate or contradict empirical trends derived from statistical analyses of trends in wildlife, livestock and human population numbers in the GMME.

Materials and Methods

This study was conducted across four zones constituting the GMME (7,500 km², Figure 1). We
adopted a mixed methods approach that combined aerial survey and human population census data with qualitative and quantitative household level data. The aerial monitoring survey data were collected from 1977 to 2018 by the Directorate of Resource Surveys and Remote Sensing of Kenya (DRSRS) on the population sizes of wildlife, livestock, and humans (Veldhuis et al., 2019). The human population censuses were conducted at the sub-locational level by the Kenya National Bureau of Statistics (KNBS) in 1962, 1969, 1979, 1989, 1999, 2009 and 2019. Interviews with both structured and open questions were administered to respondents in July 2019 and 2020 in the GMME. The interviews which were part of a larger study captured a wide range of themes. We focus on the responses on demographic and livelihood characteristics as well as local perceptions of trends in livestock, wildlife and human population sizes.

![Figure 1: Map of the study zones](image)

The interviews (=338) consisted of 227 male household heads and 111 female spouses of the household heads or household heads themselves. Three of the four zones of the GMME were each partitioned into 5×5km units and one household selected randomly from each unit for interview in July 2019 and July 2020. For each unit a different household from the one interviewed in 2019 was selected for interview in 2020. Only rangers and wardens were interviewed at each of the five main entrance gates of the Mara Reserve. To account for perception differences, respondents were distributed over the four zones such that 37 were from the Mara Reserve gates, 129 from the conservancies zone, 87 from the Loita Plains and 85 from Siana. The interviews were conducted by 10 trained residents who were familiar with both the geographic terrain and spoke the local Maa language.

## Results

### Household Demographics

Most respondents lived in permanent homesteads, with those from Siana living on larger land parcels than their counterparts from the other three zones. Over 50% of the household heads had no formal education. The largest proportion of educated respondents were from the Mara Reserve where more females than their male and female counterparts in the other study sites had acquired a tertiary education. This difference in gendered education reflects the sample of educated female rangers which was unique for the Mara Reserve because across all the other sites, pastoralism was the most dominant livelihood type.

### Livestock, wildlife, human population, and settlement trends

The aerial survey data showed that, on average, the total number of the 14 common large wildlife species (Thomson’s and Grant’s gazelles, impala, warthog, ostrich, waterbuck, topi, hartebeest, wildebeest, zebra, eland, buffalo, giraffe, and elephant) declined in the GMME by 72.3% from 491,368 animals in 1977-1978 to 136,364 animals in 2018. Cattle numbers also declined by 14% from 218,391 in 1977-1978 to 187,672 in 2018, whereas sheep plus goats grew exponentially by 306.4% from 165,735 in 1977-1978 to 673,606 in 2018. Many respondents (46%) perceived a decrease in wildlife populations consistent with the empirical trends, with a far smaller proportion (4%) perceiving this trend close to conservancies. Respondents attributed the declines to increased number of fences and human settlements displacing and blocking wildlife movements, as well as elevated poaching levels. However, many respondents (49%) also reported an increase in wildlife numbers during 2011-2020 contrary to the aerial survey trends, with 67% perceiving this increase within or closer to conservancies. Respondents attributed the increase in wildlife numbers with enhanced conservation efforts involving intensified protection by rangers of wildlife and their habitats.

Regarding livestock, 51% of respondents perceived a decrease in cattle numbers, corroborating the aerial survey trends. Interviewees attributed the declines to shrinking of grazing land as conservancies expanded. Respondents viewed the
shift in land tenure system from group to private ownership, subdivision and fencing as depriving communities of the benefits of traditional communal grazing and flexible mobility critical for cattle pastoralism. However, a substantial proportion (30%) of respondents perceived increased cattle numbers due to good livestock management, sufficient space, pasture and other resources and increased livestock purchases using conservancy land rents. Contrary to the aerial survey trends, interviewees reported a sharp decline in numbers of sheep (57%) and goats (54%) during 2011-2020. Respondents explained this by resource scarcity linked to loss of grazing land to expanding wildlife conservancies and strict enforcement of conservancy grazing rules. Respondents linked the perceived increase in goat (21%) and sheep (17%) numbers to sufficient grazing area and pasture and more income, e.g., from conservancy payments, for purchasing more or reducing sales of sheep and goats.

Most respondents held negative attitudes towards perceived increases in wildlife numbers. Interviewees viewed wildlife as occupying the space meant for livestock (67%) and roaming out of protected areas and onto private lands where both species compete for similar limited resources. Another negative perception concerned the removal or displacement of livestock keepers from protected areas which were former grazing areas. However, some respondents (27%) felt that wildlife does not occupy the space meant for livestock as fences keep wildlife out and enclose livestock inside private land. Yet other respondents even observed that few or no more wildlife remain, which more closely matches the aerial survey trends.

Both the aerial survey and interview data revealed consistent patterns of change in the number of people and settlements. The KNBS censuses showed a 315% increase in human population size from 38,451 people in 1979 to 144,702 people in 2019 whereas the DRSRS aerial survey showed that settlements increased by 110% from 66,874 in 1977 to 140,875 in 2018 similar to the household survey in which respondents observed an increase in human population and settlement (90%) numbers. Across all four zones, land privatization was considered the major driver of sedentarisation, leading to increase in settlements. Additionally, within the conservancies and around the MMNR, respondents (96%) reported an increase in population size over 2011-2020 due to high birth rates. Population increase within the Mara area was associated by respondents (57%) to increases in businesses, employment in tourism and other sectors and to grazing opportunities in the MMNR (especially at night in the dry season). Within or near conservancies, respondents (34%) attributed population increase to employment and grazing opportunities or arrangements within conservancies. Those who reported an increase in population size near conservancies (68%) viewed this positively and stated that rights and freedoms could be exercised under private property ownership and that inhabitants could enjoy interactions as part of a community and access development opportunities.

Discussion and Conclusions
The widespread biodiversity loss and concurrent increase in livestock numbers in Africa’s grasslands is troubling and is associated with increasing studies into community perceptions of wildlife. Exploring apparent discrepancies between empirical and perceived trends provides novel insights into the tensions characterizing human, wildlife, and livestock interactions in grasslands. For example, why did most interviewees report widespread livestock declines while aerial survey trends showed an exponential increase in sheep and goat numbers and a marginal decline in cattle numbers? The scale at which data are collected may explain this apparent discrepancy. The aerial survey was conducted at the ecosystem level (7,500 km²), whereas the interviews captured household level perceptions. Per capita, Mara residents are becoming more cattle poor. Thus, for example, cattle numbers per person sharply declined from 6 (210,586 cattle/34,851 people) in 1979 to 1.5 (223,067 cattle/147,702 people) in 2019. The number of sheep and goats per capita also declined from 5.5 (193,215 sheep and goats/34,851 people) in 1979 to 4.4 (635,393 sheep and goats/147,702 people) in 2019. This explains the apparent paradox of the survey respondents’ perception of a decline in sheep and goats at the household level despite the exponential increase in their numbers at the ecosystem level.

Despite the high level of investment in wildlife conservation in Kenya, our results imply that payment for ecosystem services approaches may undermine overall conservation outcomes in grasslands. According to the respondents, income from conservancy payments contributed to increased livestock purchases and reduced animal sales by Mara residents seeking to maintain or expand their livestock wealth. Given finite land and other resources, our results complement emerging evidence from various studies which warn against increased pressure on grasslands from growing livestock numbers and expanding land under conservancies without careful
consideration of the trade-offs for other human sustainable development goals.

A second apparent discrepancy regards the perception that wildlife numbers are increasing whereas the aerial survey trends show the opposite pattern. One explanation for this is linked to the expansion of conservancies. Since the adoption of the Wildlife Act of 2013 by Kenya’s parliament, 6.36 million ha of land has been officially recognised as under private or non-state wildlife conservancies Kenya-wide, and 2.4 million ha of conservancies are proposed or are in the process of formation (KWCA, 2016). Given the exponentially increasing human population and settlement numbers established from both the household and aerial surveys, human-wildlife conflicts (HWC) are increasing, accentuating the impression that wildlife numbers have increased, especially near protected areas. Increases in human and livestock numbers are positively associated with increases in HWC in Narok county and Kenya-wide (Mukoka et al, 2019). HWC are considerably high because, over 65% of Kenya’s wildlife are found outside protected areas and around 30% in Narok County (Ogutu et al, 2016). Fencing land is regarded as one way of reducing HWC (Løvschal et al., 2017). But the rapid increase in fencing has had devastating impacts on biodiversity and ecosystem function threatening the near complete collapse of wildlife populations and flexible traditional pastoralism in this ecosystem while escalating conflicts. The drivers of fencing are not limited to minimization of livestock depredation and crop-raiding but also include active resistance against land dispossession and enhancing land tenure security (Weldemichel and Lein, 2019). The respondents also accurately perceived increases in wildlife numbers inside some conservancies as human activities displace wildlife from the unprotected parts of the GMME, despite the overall ecosystem-level decrease in wildlife revealed by the aerial surveys.

Capturing local perceptions and evaluating them against empirical trends is essential for understanding attitudes toward conservation, pastoralism and other livelihood and development goals. In aggregate, our results demonstrate that perceptions of temporal trends are scale-dependent, and that scale should be considered in interpreting such perceptions to avoid creating apparent paradoxes. They further suggest that wildlife conservation initiatives should be synergistic with incentives that enhance human welfare otherwise they risk creating trade-offs and being viewed as less attractive than conservation-incompatible incentives, such as encouraging increasing human and livestock population numbers. If human-dominated grasslands are to continue sustaining vibrant livestock and wildlife populations, then the different values attributed to wildlife and livestock should be understood, reconciled and integrated into policies. Our results additionally suggest that incentives—whether financial or otherwise—that support human livelihoods in wildlife-rich human-dominated grasslands must accompany the expansion of conservancies with socioeconomic advancement of residents to reduce the risk of poverty likely to result from replacing livestock with wildlife without providing viable alternative livelihood options and minimising resentment against wildlife conservation efforts. Such investments are however necessary even without expanding conservancies because of rapid human population increase in many grasslands, including the Mara, and simultaneous declining per capita livestock holdings.

Acknowledgements

We thank the respondents and enumerators for contributing their valuable time and insights. We also thank the Director of the DRSRS, Dr. Patrick Wargute, for generous support with field logistics and permission to use the DRSRS data. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No.641918 through the AfricanBioServices Project and from the German Research Foundation (DFG, #257734638).

References


Weldemichel TG, Lein H. 2019. “Fencing is our last stronghold before we lose it all.” A political ecology of fencing around the Maasai Mara National Reserve, Kenya. *Land Use Policy*, Sep 1;87:104075.


THEME 5. DROUGHT MANAGEMENT AND CLIMATE CHANGE IN RANGELANDS /GRASSLANDS

Topic: Land use, Carbon Sequestration and GHG fluxes
Exploring water use and production dynamics of indigenous protected Sikumi forest in south western Zimbabwe

Gwate, O

Lupane State University, Off Victoria Falls Road, Lupane, Zimbabwe

Key words: Indigenous forest; evapotranspiration; ecosystem functioning; climate change; measures of ecosystem stability

Abstract
Monitoring changes in carbon and water vapour fluxes over a landscape helps understand ecosystem functioning and improves vegetation management. To understand potential shifts in ecosystem functioning, MoDerate Resolution Imaging Spectroradiometer (MODIS) evapotranspiration (ET), net photosynthesis, gross primary production and net primary production data were explored in Sikumi forest dominated by three species clusters (Teak forest woodland, Miombo woodland and savannah, and Vachellia). Measures of ecosystem stability, including water use efficiency (WUE), rainfall use efficiency (RUE), evaporative index, and carbon use efficiency (CUE), were assessed for trends and step changes together with rainfall and evapotranspiration data. Miombo woodland and savannah had significantly higher actual ET and production compared to Vachellia and Teak clusters. Ecosystem production was strongly coupled with precipitation as the Vachellia and Teak clusters became carbon sources during the dry season. Even during the dry season, high production in the Miombo cluster could be linked to xylem rehydration and convergent evolution to harvest additional water and nutrients. Annual net primary production in Sikumi forest was 632±189 g C m⁻². Despite relatively small spatial coverage (12%), the Vachellia cluster contributed production similar to the Teak and Miombo woodlands clusters that covered 63 and 25% of the forest area, possibly due to soil fertility. Teak had the highest CUE (62%) but lowest NPP, possibly due to high respiration. The relationship between rainfall, NPP and measures of ecosystem stability was unimodal. This provided insights into the likely trajectory of these indices within the purview of climate change. The low RUE of the Teak cluster suggests that this cluster was more sensitive to disturbance. The study area was water-limited, as shown by a low ETa/PET ratio. Monitoring carbon and water flux dynamics help to identify the onset of ecosystem change and may inform requisite interventions to improve ecosystem functioning.

Introduction
Autotrophs produce new biomass via the process of photosynthesis. This process typifies the close coupling between the carbon and water cycles, which are essential for ecological functioning and the provision of ecosystem services (Murray et al., 2019). During photosynthesis, plants release water vapour through evapotranspiration (ET) for atmospheric carbon. ET rates are closely related to the carbon fixation rates of plants and can be used as an indicator of plant ecological functioning for vegetated land surfaces. Net primary production typifies this new biomass created over time and is critical in evaluating ecosystem functionality. Evapotranspiration is the combined process of water loss from the soil, surfaces and transpiration. Transpiration relates to water vapour loss via the small pores on leaf surfaces called stomata. Through links between stomatal conductance and carbon exchange, plant ET regulates key ecosystem processes. It provides insights into ecologically important aspects of climate-linked to energy supply, water balance and plant productivity. Within the context of global environmental changes, it is vital to evaluate the performance of each landscape in terms of plant–atmosphere exchanges as it helps to predict earth system processes (Murray et al., 2019).

Forests are critical in attenuating global warming since they sequester carbon via the process of photosynthesis. In addition, they play an important role in producing and regulating the world’s temperatures, freshwater flows and other ecosystem services. Therefore, the maintenance of healthy forests is critical for human wellbeing. Globally, indigenous forests are under pressure...
from degradation, climate change, and human appropriation of net primary production. As a result, most patches of indigenous forests have been transformed. Zimbabwe prides itself as a country with remarkable quantities of indigenous forest. In Zimbabwe, the dynamics in water vapour and carbon fluxes have not been adequately described, especially over indigenous forests. Even in neighbouring Zambia, there is a dearth of studies that focus on water vapour and carbon fluxes and hence it is important to investigate these dynamics at the lower rainfall end gradient of the indigenous forest belt of Southern Africa. The Zimbabwean situation is also unique in that buffer zones that had been left around gazetted forests have been compromised by resettling people during the watershed fast track land reform programme in 2000. This has consequently increased disturbances in protected forests, affecting water vapour and carbon dynamics.

Some of the unifying concepts in terms of diagnosing ecosystem stability include water use efficiency (WUE) or rainfall use efficiency (RUE), evaporative index and carbon use efficiency (CUE). Unfortunately, there is a paucity of ecological observation infrastructure in southern Africa to effectively monitor ecosystems functioning. However, with the growing availability of satellite data to support ecosystem monitoring, it becomes possible to analyse spatial-temporal dynamics in these measures of ecosystem stability. The study explores water vapour, and carbon dynamics in Sikumi protected indigenous forest in southwestern Zimbabwe.

Materials and Methods

Study site

The study area encompasses 54 400 ha Sikumi forest in Matabeleland North province, Zimbabwe. The study area is an indigenous forest that is gazetted and protected under the Forest Act Cap 19:05. The Forestry Commission of Zimbabwe conveniently divided the forest reserve into clusters based on species dominance. These include the *Baikiaea plurijuga* or Zambezi teak woodland forest cluster (63%), followed by Miombo woodland and savanna cluster (25%), and the *Vachellia* spp cluster (12%). An important feature is that the Sikumi forest lies predominantly on Kalahari Sands geological formations characterised by deep sandy soils. The *Vachellia* cluster occupies extensive areas within the forests with eutrophic soils developed from base-rich geological formations.

Evapotranspiration and rainfall data

To compute ET, we accessed the MOD16 ET product from the DAAC website (https://lpdaac.usgs.gov/). The Tropical Applications of Meteorology Using Satellite Data and Ground-Based Observations (TAMSAT) (Tarnavsky et al., 2014) was also used to compute rainfall. The data was accumulated into annual sums and eight-day sums to be consistent with MODIS products to facilitate easy analysis. The annual pattern of ET and rainfall data were tested for the presence of trends using the Mann-Kendall trend test and step-change using the Pettitt or median change point between the years 2000 and 2018. Detecting changes in ET data is useful in determining ecosystem functioning in terms of water vapour fluxes.

Net primary production and water use efficiency

We also accessed the MOD17A2 and MOD17A3 products (https://lpdaac.usgs.gov/) to determine carbon sequestration in the vegetation stand. The correlation between rainfall and net photosynthesis (PsnNet) and the MOD17A3 were explored to help uncover the influence of rainfall on carbon capture. Subsequently, the WUE, RUE, CUE was computed.

Measures of ecosystem stability

WUE, RUE, evaporative index and CUE were determined to assess ecosystem resilience. Subsequently, the Mann-Kendall trend test and Pettitt tests were applied to these indices. In addition, the relationship between these indices and precipitation was explored. Finally, the Kruskal Wallis test was applied to test for any significant differences at a 95% confidence interval.

Measures of ecosystem stability

WUE, RUE, evaporative index and CUE were determined to assess ecosystem resilience. Subsequently, the Mann-Kendall trend test and Pettitt tests were applied to these indices. In addition, the relationship between these indices and precipitation was explored. Finally, the Kruskal Wallis test was applied to test for any significant differences at a 95% confidence interval.
Results

Water flux

Over the 18-year study period, eight days mean ETa ranged from 11 to 22.5 mm across different species clusters, while the average eight-day rainfall was 1.82 mm. The average ETa for the Miombo cluster was significantly higher (p < 0.001) than that of the Vachellia and Teak clusters, while ETa from the latter two was similar. Rainfall was similar across species types, and it was the most variable water flux followed by ETa from the Vachellia, Teak and finally that of the Miombo cluster. The averaged 8-day ETa followed the rainfall pattern, although a significant amount occurs during the long winter dry spell, particularly for the Miombo woodland and savannah cluster. ETa for Teak woodland ranged from 2.5 to 23.3 while that for the Miombo woodland and savanna cluster ranged from 11.7 to 37.7 mm, and that of Vachellia cluster ranged from 1.5 to 28.7 mm per 8-day period. On an annual basis, the average ETa for the Teak forest and woodland cluster (503.2±106 mm) was significantly (p < 0.05) lower than that from that of Miombo woodland and savannah cluster (572.71±116) and marginally (p < 0.1) different from that of the Vachellia cluster (563±111). PET was consistently higher than ETa, with an average ETa/PET of 0.22 over the eighteen-year study period. Annual ETa was relatively low during periods of high (>750 mm) rainfall and relatively higher during periods of lower (< 750 mm) rainfall.

The pattern of carbon fluxes

Production occurred throughout much of the year despite marked seasonality in the long-term rainfall pattern. Vachellia and Teak woodland became carbon sources by DoY 273 while the Miombo woodlands and savannah cluster remained productive with a minimum of 6.8 g C m-2 eight day-1 periods. Average Net photosynthesis for the Miombo and savannah woodlands (26.3±11) was significantly higher (p < 0.01) than that of the Vachellia (16.4±11) and Teak (15.8±100) clusters. The coefficient of variation for Miombo (41%) was relatively lower than that of Teak (63%) and Vachellia (67%). On an annual basis, the average NPP for Sikumi forest was 632± 189 g C m-2. Production from Miombo (645.4±192 g C m-2) was higher than that of Vachellia (631.6±194 g C m-2) and Teak (619±181 g C m-2). The annual rate of change in NPP for the Vachellia and Miombo cluster was 14 g, while for the Teak Forest, it was 13 g C m-2. Over the study period, Miombo woodland and savannah (12.3 C Kg m-2) contributed the highest amount of carbon, followed by Vachellia (12 Kg C m-2) and finally Teak Forest and woodland (11.8 kg C m-2). Across all the studied species clusters, rainfall and NPP displayed a polynomial relationship. Beyond annual rainfall of 700 mm, NPP began to decline.

Measures of ecosystem stability

The Teak and woodland forest had a relatively lower evaporative index than Miombo and Vachellia species clusters. The Teak Forest had the highest WUE (p < 0.05) during the study compared to Miombo woodland and savannah and Vachellia clusters. No trend was detected in the evaporative index of clusters though Kindall’s tau was positive. The Teak Forest and woodland’s CUE was significantly higher (p < 0.001) than that of Miombo and savannah but similar to that of the Vachellia cluster. WUE, CUE, and RUE were strongly coupled to rainfall. However, when rainfall exceeded 700 mm, they all began to decline.

Discussion and Conclusions

Influence of species cluster on water and carbon dynamics

Despite marked seasonality of rainfall, a significant amount of ETa, especially for the Miombo cluster, took place during the dry season when rainfall was negligible. This suggests that such vegetation could be accessing groundwater or has high water storage potential to support ecosystem processes. However, not all trees may access groundwater given the very low water table in the Kalahari Sands. The apparent pre-rainfall greening in the savannah could suggest that additional water comes from a plant storage system or groundwater (Ryan et al., 2017). This pre greening could be explained by vegetation convergent evolution linked to xylem rehydration at the height of the dry season owing to the long-distance xylem transport (Vinya et al., 2018). The ETa/PET ratio was 0.22, indicating that the area was water limited.

In terms of carbon, the Miombo woodland and savannah cluster remained productive during extremely dry conditions, while the Vachellia and Teak and woodland became carbon sources. The high productivity of the Miombo cluster suggests that the trees could have been accessing additional water by deploying a number of strategies such as deep roots as well as lateral roots that enable it to effectively harness water and nutrients ( ). The mean annual NPP was lower than the 9 to 12 tons ha-1 reported for Miombo woodlands of Zambia (Day et al., 2014). Although the Vachellia cluster covered only 12% of the area, it contributed average cumulative NPP similar to Miombo.
woodland and savanna and Teak over the 18 years, suggesting that the species cluster was critical in the water and carbon dynamics of Sikumi forest.

Many studies have found a positive relationship between rainfall and NPP since increased rainfall improves water supply and the process of photosynthesis. Admittedly, temperature influences NPP but in the study area, the temperature was not limiting, as shown by the low ETa/PET ratio as well as the consistently higher PET compared to ETa. The unimodal relationship between rainfall and NPP suggests convergent evolution of the trees species in this area to reach optimal production at around 700 mm of annual rainfall. We postulate that beyond 700 mm high nutrient leaching in these Kalahari Sands derived soils undermine plant nutrient absorption.

**Ecosystem stability**

The relationship between ETa and rainfall was consistent with the well-established theoretical framework that during periods of low rainfall, the evaporative index tends to be relatively higher than high rainfall times (Zhang et al., 2001). The evaporative index was occasionally > 1 or even at unity suggests that the plants had access to additional moisture probably from underground or moisture stored in the plant system in the deep Kalahari Sands. Therefore, governments should consider commercial cultivation of Teak given its high WUE than leaving it to grow naturally in demarcated forests. A relatively lower amount of rainfall falling on Teak was used in plant biomass production compared to the Miombo woodland and savannah and *Vachellia* clusters. Hence, besides rainfall, other factors (anthropogenic, nutrients) had more impact on vegetation production than the Teak cluster than the *Vachellia* and Miombo clusters. This suggests that Teak could be more sensitive to disturbance than other clusters.

About 55% of photosynthetic production was assimilated into new plant biomass in the Sikumi forest. This was higher than the global average of 45% (He et al., 2018). The Teak cluster had the highest CUE, suggesting that it had the higher carbon conversion efficiency and, therefore, was critical in attenuating global warmings. We found relatively high CUE (0.43 – 0.62), and this was similar to results reported elsewhere (0.47 – 0.6) (Chen and Yu 2019). In the context of increasing atmospheric CO2, Teak would be critical in carbon sequestration. Hence, Teak could play a more important role in attenuating global warming. Therefore, maintenance of the vegetation will be critical not only for the timber industry but also for global change science. However, the relatively lower NPP of Teak compared to other clusters suggests potentially higher respiration in Teak.

Neither trends nor step changes were detected in the evaporative index, WUE, RUE and CUE in Sikumi forest, suggesting that the ecosystem remained relatively stable during the study period. The stability of these ecosystem indicators suggests that the ecosystem is resilient and no marked changes are taking place. Rainfall was strongly coupled with water vapour and carbon fluxes in the study area. However, as soon as rainfall reached 700 mm, WUE, CUE and RUE began to decline because optimum productivity conditions will have been surpassed.

In conclusion, water use and carbon assimilation at Sikumi forestry were strongly coupled with the rainfall input. However, production, especially for the Miombo woodlands cluster, continued during the dry season, possibly due to xylem rehydration and access to groundwater. Despite the Teak cluster’s high carbon conversion efficiency (62%) and large spatial coverage, it contributed the least in terms of NPP owing to possibly high respiration in the cluster. The anticipated reduction in mean annual rainfall in the study site is likely to result in a decline in these ecosystem indicators, and a deterioration in ecosystem services at Sikumi forest since the relationship between measures of ecosystem stability and rainfall was unimodal. The stability of these measures of ecosystem stability suggests that the ecosystem was resilient during the study period. As shown by low rainfall use efficiency, the Teak cluster was more sensitive to disturbance than other clusters. Therefore, it is critical to continuously monitor the study’s carbon and water flux dynamics to help identify the onset of ecosystem change and make requisite interventions to improve ecosystem functioning.

---

**References**


Long-term N addition, not warming, increases net ecosystem CO$_2$ exchange in a desert steppe in northern China

Han, G$^1$; and Wu, Qian$^1$

$^1$College of Grassland, Resources and Environment, Key Laboratory of Grassland Resources of the Ministry of Education, Key Laboratory of Forage Cultivation, Processing and High Efficient Utilization of the Ministry of Agriculture and Rural Affairs, Inner Mongolia Key Laboratory of Grassland Management and Utilization, Inner Mongolia Agricultural University, Hohhot 010011, China

Key words: C$_3$ and C$_4$ plants; desert steppe; ecosystem CO$_2$ flux; global warming; nitrogen deposition

Abstract

Grasslands cover a major part of the global terrestrial area and provide important ecosystem functions such as sequestration of carbon (C). Desert steppes are unique ecosystems with properties in between desert and grasslands. They are considered to be vulnerable ecosystems that are at risk of desertification due to global change. To provide a robust prediction of the effect of climate warming and increased nitrogen (N) deposition on desert steppe, long-term studies that capture the annual variation in precipitation are needed. We conducted a 12-year field experiment in a desert steppe which showed that warming did not change ecosystem C exchange whereas N addition increased ecosystem C storage. Moreover, warming did not change total aboveground biomass, mainly due to the contrasting responses of C$_4$ and C$_3$ plants, especially in the presence of additional N. Therefore, our study predicts that warming do not necessarily lead to degradation of the desert steppe and N addition may have a positive effect on CO$_2$ sequestration, providing a negative feedback on climate change. However, these global change drivers do alter vegetation composition in the desert steppe, which can have consequences on a diversity of ecosystem functions.

Introduction

Grasslands cover 41% of the earth’s land surface and contain about 34% of terrestrial carbon (C) stocks (White et al., 2000). Global warming and elevated levels of nitrogen (N) deposition are two of the most important factors affecting ecosystems (Boutin et al., 2017; Lin et al., 2010). Both increased temperature and N deposition can significantly affect plant growth and the carbon (C) cycle with potential feedback effects on climate change (Liu et al., 2018; Peng et al., 2017).

Net ecosystem CO$_2$ exchange (NEE), the difference between gross ecosystem productivity (GEP) and ecosystem respiration (ER), indicates whether the grassland ecosystem is a carbon sink or source (Öberbauer et al., 2007; Xia et al., 2009). Warming or N addition may increase (Niu et al., 2009), decrease (Jiang et al., 2012) or not affect NEE (Xia et al., 2009), and thus might have a positive, a negative or no effect, respectively, on climate change. These and several other studies show that the effects of warming and N addition on NEE depend on ecosystem type (Shi et al., 2015; Xia et al., 2009), and there has been no study on desert ecosystem so far. Furthermore, relatively few long-term warming and N deposition studies have been conducted, and the interactive effects of N deposition and warming on ecosystem CO$_2$ fluxes in the desert steppe are not well understood.

Warming and N addition can also affect NEE by changing the relative abundance of species within grassland plant communities (Chen et al., 2016; Xu et al., 2015; Zhang et al., 2015). This might involve changes in the relative abundance of C$_3$ versus C$_4$ species (Song et al., 2012; Xu et al., 2014), and such changes in their composition have been shown to be correlated with ecosystem CO$_2$ fluxes (Niu et al., 2013; Xu et al., 2015). The growth of C$_3$ species is in general more constrained by low N conditions and it seems probable that additional N application would stimulate their growth more than that of C$_4$ species (Gowik and Westhoff 2011). However, C$_4$ species could have a better adaptation on warmer conditions than C$_3$ species (Gowik and Westhoff 2011). As warming and N application might have opposite effects on the growth of C$_3$ and C$_4$ species, it is of special interest to determine their combined effect.
The desert steppe is an important and unique part of the steppe in Mongolia and northern China (Inner Mongolia), and is considered to be a fragile ecosystem and probably at risk to desertification due to global change (Angerer et al., 2008). It plays an important role in C sequestration, biodiversity, animal husbandry and regional economic development. Therefore, it is important to study the effects of warming and elevated levels of N deposition on the desert steppe. In this current study, we conducted a long-term (12 years) field experiment in a desert steppe in northern China to examine the effects of warming and N addition on ecosystem CO$_2$ flux and the aboveground biomass of two photosynthetic types ($C_3$ vs. $C_4$ plants), to explore if there was a long-term individual effects as well as interactive effects of warming and N addition on ecosystem CO$_2$ fluxes and how this relates to an effect on the aboveground biomass of $C_3$ versus $C_4$ species.

**Materials and Methods**

**Study Site**

The study was conducted at Siziwang Banner (41°46′43.6″ N, 111°53′41.7″ E, at 1456 m above sea level); an arid region in Inner Mongolia in northern China. We used a split-plot design with warming as the main plot and N addition as the subplot. One plot in each pair was assigned to warming (W1) and the other was maintained at ambient temperature (W0, or no-warming). Each main plot was divided into two 2 m × 3 m subplots, one of which was randomly assigned to receive supplemental N (N1) and the other received no additional N (N0). Thus, 24 subplots were established with the following treatment combinations: no-warming without N addition (W0N0), no-warming with N addition (W0N1), warming without N addition (W1N0) and warming with N addition (W1N1), with each treatment combination replicated six times. Each year, N was applied prior to a rainfall event in about the third week of June using granular NH$_4$NO$_3$ (10 g N m$^{-2}$ yr$^{-1}$). Each warmed plot was heated continuously starting from May 2006 using a 165 cm × 15 cm MSR-2420 infrared radiator (Kalgo Electronics, Bethlehem, PA, USA). The infrared radiator was hung 2.25 m above the ground in the warming plot and was set at an electrical power output of 2000 W. In the non-warming plots, a dummy radiator of the same size was hung at 2.25 m height to simulate the shading effect of the heater.

Ecosystem CO$_2$ fluxes were measured with a transparent chamber (0.5 m × 0.5 m × 0.5 m) attached to an infrared gas analyzer (IRGA; LI-6400, LiCor Biosciences, Lincoln, NE, USA). Ecosystem CO$_2$ fluxes were measured on sunny days between 9:00 am and 12:00 pm once or twice a month across the growing seasons from 2007 to 2018. A permanent 1 × 1 m quadrat was established in each of the 24 subplots. In each quadrat, visual estimates of plant canopy cover of each species were made with the aid of a 10 cm × 10 cm grid in late August (at peak plant biomass, 2007 to 2018). We employed a nondestructive method to estimate the biomass of each species to minimize the disturbance to the plots. Forty locations outside the study plots were randomly selected and a quad was placed at each location to measure the cover of each species. We then clipped all the aboveground plant materials of each species in the quadrat, and the samples were oven-dried at 65 °C for 48 h and weighed. We developed regression equations for each year between biomass and cover for each species with data from the forty quadrats. Finally, we estimated aboveground biomass of each species in the quadrat of the experimental plots using the equations established for each year. Total aboveground biomass was the sum of aboveground biomass of each species in August.

![Figure 1](image-url)
Results

Warming and N addition effects on aboveground biomass of C$_3$ and C$_4$ species

Across the 12 years, total aboveground biomass was increased by N addition ($F_{1,10} = 12.62; P = 0.005$), but was not affected by warming ($F_{1,10} < 0.01; P = 0.951$) or the interaction of warming and N addition ($F_{1,10} < 0.01; P = 0.940$). Warming had significant but opposite effects on the aboveground biomass of both C$_3$ and C$_4$ plants, especially when N was added (Fig. 1). The biomass of C$_3$ species was reduced whereas that of C$_4$ species was increased (W0N1 vs W1N1) ($P < 0.05$; Fig. 1). However, there were no interactive effects of warming and N addition on C$_3$ and C$_4$ species across the 12 years (Fig. 1).

Warming and N addition effects on ecosystem CO$_2$ exchange

Ecosystem CO$_2$ fluxes, including NEE, ER and GEP, had strong inter-annual variations (Fig. 2). N addition increased NEE ($F_{1,10} = 13.00; P = 0.005$; Fig. 2) and GEP ($F_{1,10} = 6.48; P = 0.029$; Fig. 2), but warming and the interaction of warming and N addition had no effects on them. However, the average ER was not significantly altered by warming, N addition or their interaction (Fig. 2).

Discussion

During the 12 years of this study, we observed that long-term warming did not change net ecosystem C exchange, but N addition did significantly increase the capacity of the desert steppe to sequester CO$_2$ (Fig. 2). Thus, the ecosystem C flux in the desert steppe was resistant to climate warming, but was sensitive to N addition. However, warming affected the composition of the vegetation as it increased aboveground biomass of C$_4$ species, but decreased that of C$_3$ species (Fig. 1). The unchanged ecosystem carbon flux under warming could be caused by the unchanged total aboveground biomass due to the opposite responses of C$_3$ and C$_4$ species. The increased net ecosystem CO$_2$ exchange induced by N addition correlates with increased total aboveground biomass regardless of warming.

N addition is one of the most limiting nutrients in grassland, so the effect of warming may have less impact on ecosystem functioning when available N is limiting. Addition of N caused a significant increase of total aboveground biomass under both ambient and warming conditions. The increase under ambient conditions was especially contributed by C$_3$ species, whereas at elevated temperature it was especially contributed by C$_4$ species (Fig. 1). The increase in aboveground biomass of C$_4$ plants under ambient conditions is well in line with general theoretical predictions, as C$_3$ plants have a lower N use efficiency than C$_4$ species (Gowik and Westhoff, 2011). Therefore, the low level of available N seems to be limiting for the growth of C$_3$ plants but not for C$_4$ plants. Under warming conditions, available N increased in most years. However, it did not lead to an increased biomass of C$_3$ plants, probably because they are less adapted to increased temperature than C$_4$ species (Gowik and Westhoff, 2011). The biomass of C$_4$ plants increased by the addition of N under warming conditions, indicating that under these conditions N availability has become limiting for these species.

It has been reported that the warming effects on CO$_2$ fluxes are likely caused by changes in plant community structure (Chen et al., 2016; Xia et al., 2009; Xu et al., 2015). However, average CO$_2$ fluxes in our desert steppe were not affected by warming alone, which is consistent with the only slight changes observed in plant community composition under warming conditions. Therefore, compared with other grassland ecosystem, the desert steppe seems to be less sensitive to warming. This is counter intuitive as desert steppe is relatively species-poor compared to the temperate grasslands, and according to
the portfolio theory higher species richness is predicted to cause less fluctuation in parameters like biomass (Lehman and Tilman, 2000). The desert steppe is located in a region with high temperature during the growing season and plants in this ecosystem might have a better tolerance to the “slight” increases in temperature due to climate change than species from temperate areas. We hypothesise that this might also be true for other desert grasslands.

NEE and GEP were significantly increased by N addition in our study and similar results were obtained by studies in a temperate steppe (Xia et al., 2009) and a meadow steppe in northern China (Jiang et al., 2012). The increase in average GEP (and NEE) by N addition correlates well with total aboveground biomass. The addition of N under both warming and ambient conditions led to a net increase, or was equal to the control treatment in all years (Fig. 2). In contrast, warming alone led to positive and negative changes in NEE which resulted in average values across the 12 years that were equal to that of the control. These positive and negative changes of NEE could be due to the water availability in each year.

Our study indicates that long-term warming does not change net ecosystem carbon flux but N addition does promote carbon sequestration in the desert steppe by which it could provide a negative feedback on climate change. Surprisingly the desert steppe, as one of the most arid grasslands in the Eurasian temperate steppe, appeared to be less vulnerable with respect to warming and N addition, and it is probable that these global changes will not cause degradation of the desert steppe. The observed shift towards C₄ species probably has no effect on the suitability of the desert steppe for animal husbandry because most of the C₄ species in the desert steppe. In combination with the increased plant productivity, change in species composition might improve the conditions for sustainable animal husbandry and continued economic development in this pastoral region.

Acknowledgements
This research was financially supported by the Innovative Research Team of Ministry of Education of China (IRT_17R59), the Inner Mongolia Key Project (zdzx2018020), and the National Natural Science Foundation of China (31660679, 30860060, 31760146).

References


Quantifying greenhouse gas emissions attributable to smallholder livestock systems in Western Kenya: cradle to farm gate life cycle assessment

Ndung’u, P.W.1,2; Takahashi, T.3,4; du Toit, C.J.L.1; Robertson-Dean, M.2; Butterbach-Bahl, K.2; McAuliffe, G.3; Merbold, L.2; Goopy, J.P.1,2,7

1Department of Animal and Wildlife Sciences, University of Pretoria, 0002, South Africa
2Mazingira Centre, International Livestock Research Institute, P.O. Box 30709, Nairobi, Kenya
3Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
4University of Bristol, Langford House, Langford, Somerset, BS40 5DU, UK
5School of Mathematics, University of New England, Armidale, NSW, Australia.
6Institute for Meteorology and Climate Research, Atmospheric Environmental Research, Karlsruhe Institute of Technology, D-82467 Garmisch-Partenkirchen, Germany
7corresponding author

Key words: quantile regression; African livestock systems; emissions intensity; greenhouse gas emissions; primary data

Abstract

Ruminants are central to the economic and nutritional life of much of sub-Saharan Africa, but cattle are now blamed for having disproportionately large negative environmental impact through (amongst other things) emissions of greenhouse gases. However, the exact mechanism behind these emissions is not well-understood and indeed accurate estimates themselves are lacking due to a paucity of reliable data. Employing individual animal records obtained at regular farm visits, this study quantified emissions intensities (EIs) of smallholder farms in three counties of Western Kenya through life cycle assessment (LCA). Crude protein (CP) was chosen as the functional unit to capture outputs of both milk and meat. The results showed that milk is responsible for 80-85% of total CP output. Farm EI ranged widely from 20- >1,000 kg CO2-eq/kg CP and median EIs were 60, 71 and 90 kg CO2-eq/kg CP for Nandi, Bomet and Nyando respectively. EIs referenced to milk alone revealed that while the median EI for Western Kenya (2.3 kg CO2-eq/kg milk) was almost twice that reported for Europe, up to 50% of farms had EIs comparable to the mean Pan-European EIs. Enteric CH4 contributed >95% of emissions and manure ~4%, with negligible emissions attributed to input to the production system. Collecting data from individual animals on smallholder farms enabled the demonstration of an extremely heterogenous EI environment amongst smallholder farms and provides clear indicators on how to achieve low EIs in these environments. Contrary to some current belief, our data show that industrial- style intensification isn’t required to achieve low EI, and that this can be achieved in a low input environment. Enteric CH4 production overwhelmingly drives farm emissions in these systems and, as this is strongly collinear with nutrition and intake, effort will be required to achieving an “efficient frontier” between feed, emissions and animal productivity.

Introduction

Livestock plays an important role in social and economic growth of Africa (Herrero et al., 2013). Driven by steady increases in population, gross domestic product (GDP), and household incomes (Steinfeld et al., 2006), demand for livestock products is rapidly growing (Thornton, 2010), with consumption of beef and milk forecast to increase by 261% and 399% respectively, between 2010 and 2050 (FAO, 2017). At the same time, supply of livestock products in Africa is constrained by competition with other sectors for scarce natural resources, suboptimal animal husbandry practices, and unreliable availability and quality of feed (Thornton 2010; Nkonya et al., 2016). Environmentally, these challenging conditions have resulted in an unusually high proportion of regional anthropogenic greenhouse gas (GHG) emissions attributed to animal agriculture, namely at 25% compared to the global average of 14.5% (Gerber et al., 2011; Gerber et al., 2013).

To date, the exact mechanism behind these high livestock emissions in the sub-Saharan African region — or the accuracy of these estimates
for that matter — is not clearly understood. This is primarily the case as most GHG inventories in Africa have been collated using the Intergovernmental Panel on Climate Change (IPCC) default (Tier I) emission factors (EF), an annual estimate of GHG emissions per head for each class of animals. While this approach is often necessitated by a lack of detailed field data to produce country-specific EFs, it is subject to a large degree of uncertainty in the presence of locally and seasonally variable animal phenotypes and feed baskets, two conditions that are almost always met in the local smallholder context (Herrero et al., 2013; Goopy et al., 2018).

Nonetheless, accurate estimation of per head EFs alone do not capture the entire variability in climate impacts across smallholder livestock farms (Goopy et al., 2018; Ndung’u et al., 2019), because in a production environment where production per animal also varies, a farm’s overall GHG performance is better assessed by emissions intensity (EI) (Moran and Wall 2011) considering all material input into and output of the system under the life cycle assessment (LCA) method (ISO 2006). This view is particularly pertinent to agricultural systems where the presence of unproductive livestock owned for a variety of non-economic reasons has been suggested as a major cause of large on-farm emissions (Weiler et al., 2014). Paradoxically, however, these systems are the ones with the greatest potential to mitigate GHG emissions simply via improved productivity, and therefore among the most important to examine in detail (IPCC 2007).

Using animal-level data collected across multiple seasons on 313 smallholder livestock farms in Western Kenya, this study elucidates the distribution of farm-level EIs as well as their determinants. Although dairy farming is the most developed agricultural sub-sector in Kenya, unintuitively it is predominantly supported by smallholders in rural areas (Muriuki 2013). In particular, Western Kenya’s Central and Rift Valley highland regions produce 60% of the country’s milk supply (Muriuki 2013), and their systems are representative of the wider East Africa where livestock is an integral part of mixed agriculture that has a dual purpose of domestic food production and cash generation. Thus, we developed the null hypotheses that:

i) GHG EI in smallholder livestock production systems in Western Kenya do not vary between a) farms, b) AEZs or c) regions.

ii) The contribution of meat production is unimportant to overall output from these farms as measured by crude protein (CP) production, and

iii) EIs are similar to model-based estimates reported in the extant literature.

Materials and Methods

Study Site

Data used in this study were collected from 313 smallholding farms located across three counties in Western Kenya: Nyando, Nandi and Bomet. Collectively, the study region encompasses six AEZs. For each county–AEZ combination, sample farms were selected under a randomized stratified sampling procedure and data collection comprised of five visits to each farm with a 12-month period as described in Goopy et al., (2018).

A cradle-to-farm gate approach was adopted to quantify herd-level EIs associated with cattle (Figure 1). In order to eliminate the aggregation bias, or systematic underestimation of climate impacts caused by “weakest link” animals (McAuliffe et al., 2018), these values were initially calculated on an animal-by-animal basis for each season and subsequently combined across seasons and then animals in that order. Although cattle data were repeatedly recorded for a period of 12 months, which constitute the temporal boundary of this study, the herd structure of each individual farm was not always at a steady state due to movement of animals in and out of the farms in the forms of sales, purchases, and temporary relocation to other farms during feed shortages. Across the entire sample, however, this effect was assumed to be largely cancelled out due to the sufficient sample size. The primary FU for the study was set as kg CP, encompassing both meat and milk production from multi-purpose cattle. We assumed that all animals sold out of study farms were sold for meat (or sold for further rearing before being on-sold for meat). Commensurably, animals purchased onto study farms were accounted for as an offset to the gross output. Thus, the total CP yield from each animal during the study period was defined as the net growth measured by the embedded CP content plus the CP content of milk produced. To estimate the CP content of meat, a dressing percentage of 52.1% was assumed based on the locally most relevant information (Muchenje et al., 2008). Meat yield was set at 85% of carcass weight (Department of Agriculture and Rural Development 2016) with a CP content of 21% (Muchenje et al., 2008). Edible by-products (offal) were also included in the total meat CP yield to reflect the local culinary practice. These included heart, kidneys,
liver, lungs, spleen, tripe, tongue, and pancreas. The average offal yield (5.3% of LW) and its CP content (18.2%) were obtained from the literature (Nollet and Toldra 2011). In addition, FPCM (kg) (IDF, 2010) and bone-free carcass weight (kg) were adopted as auxiliary FUs to facilitate the comparison of results with single-commodity LCA studies for milk and meat, respectively. The FPCM was standardized to 4% fat and 3.3% true protein. The bone-free carcass weight was estimated using the assumptions described above.

**Figure 1**: System boundary for life cycle assessment of smallholder farms. Squares show feedstuff in the feed-basket where the sizes demonstrate the contribution of each feed to the overall feed-basket (NG: Napier grass; MS: maize stover; RG: Rhodes grass; ST: sugarcane tops), ovals show the manure management systems, shows the flow of raw materials and where the manure is deposited and → shows the farm inputs and output.

Enteric CH\(_4\) emissions were calculated according to the approach described in Goopy et al., (2018). Composite emission factors manure left on pasture (50%), in an enclosure (Boma) (25%) and in a pile (25%) for CH\(_4\) and N\(_2\)O manure were both estimated as weighted averages of the values locally measured under the three conditions. Annual gas-by-gas emissions attributable to each animal were converted to global warming potential (GWP) under the 100-year Global Warming Potential (GWP100) method, which assumes the characterization factors of 28 and 265 for CH\(_4\) and N\(_2\)O, respectively (IPCC 2013). This value was next aggregated across all animals within a single farm to estimate the farm-level GWP. Finally, the corresponding farm-level EI (CO\(_2\)-eq/kg CP) was derived as the ratio between GWP and the total (net) CP output. Initial analysis of farm EIs (n = 313) identified a small number of farms across three counties (n = 25) with nil or negative CP output, resulting in aberrant (infinitely large) EIs. Additionally, a small number of farms (n=4) with positive but very low CP outputs (<3kg CP p.a.) returned extremely high EIs (>3,000kg CO\(_2\)-eq/kg CP). With the upper bound for EIs in livestock systems posited to be ~1,000kg CO\(_2\)-eq/kg CP (Gerber et al., 2011), the decision was made that EIs above this value would be truncated. Similarly, the distribution of farm-level EIs was preliminarily studied under a variety of exploratory data analysis methods. As this revealed that the data were extremely right-skewed without a uniform variance, further investigations to explore the factors contributing to differences in EI were undertaken using quantile regression (Koenker and Hallock 2001). The following quantiles were used for the present analysis: 0.85, 0.75, 0.5, 0.25 and 0.1. with a model created for each of these quantiles. The explanatory variables considered include herd size, parity, average age (of cattle), milk yield, meat yield, and total GHG emissions. Fixed effects associated with counties and AEZs were also considered.

**Results**

**Distribution of farm EIs**

Median farm EIs were estimated to be 67, 66, and 128 kg CO\(_2\)-eq/kg CP for Nandi, Bomet, and Nyando counties, respectively. However, the values of individual farms dramatically varied even within each county. There was also substantial variation in the frequency of occurrence of low, intermediate, and high EI farms between counties and AEZs, with Nyando having the greatest proportion of high EI farms (Figure 2).

**Factors influencing farm-level EIs**

Quantile regression revealed several management features that are highly influential to EI at the farm level, irrespective of the county or AEZ. Some factors were universally important, while others only at some EI quantiles. Despite the uneven contribution to total CP outputs, both meat and milk yields were significant drivers of EI across all quantiles investigated. Mean milk yield per cow, rather than milk production per farm, was found to be the most important driver of EI, with an increase in yield associated with a decrease in EI.
An increase in herd size was found to increase EIs for low and medium EI (high and moderate performing) farms (Q10: $\beta_{HS} = 1.35, \ p < 0.005$, Q50: $\beta_{HS} = 1.86, \ p < 0.01$), whereas this tendency was not observed among high EI (low performing) farms. Although the average age of cattle was not important to EI, the proportion of females in a herd was negatively related to EI for most quantiles. The effect of calving percentage was only significant — and positive — for high EI farms ($p<0.005$). Finally, there were no clear differences in EI between AEZs, likely because the intrinsic differences were captured by other variables in the models.

Discussion
In many ways, nominal comparison of mean/median EIs between different dairy production systems obscures important findings from the present study. Firstly, our data demonstrate that meat CP makes up 15-25% of farm output across systems, and thus to ignore this would result in a substantial over-estimation of EI in smallholder farms unless emissions attributable to the ‘by-product’ (meat) are appropriately allocated out. Secondly, although a few studies have applied LCA to estimate EIs in African livestock systems (Opio et al., 2013; Weiler et al., 2014; MacLeod et al., 2018; Kiggundu et al., 2019), input data have been derived from a variety of secondary sources in every case, including post hoc farmer estimates, national census statistics, FAOSTAT databases, and modelling based on these secondary data. In contrast, the results reported herein are based on measurements of individual animals and actual feed baskets, providing a far clearer picture of the heterogeneity of farm-level EIs across counties and AEZs. This approach, in turn, led to the revelation that some 57%, 58% and 20% of the sample farms in Nandi, Bomet and Nyando achieved EIs comparable to European/North American intensified operations and, notably, without employing a high degree of intensification that is a hallmark of such systems. Characterization of the drivers of highly and less efficient farms has provided insights into the factors driving low EIs in smallholder farms, something unachievable in studies relying on secondary data. A curious finding of this study was the simultaneous presence of farms with very high and very low efficiencies, even between neighbouring enterprises. Prima facie, the differences between farms at the extremes of EI distribution were attributable to differences in CP output — very low EI enterprises had substantial outputs, whereas very high EI enterprises had little or in some cases no output at all in the course of the year. The absence of lactation and steady animal growth caused a small number of individual farms to demonstrate exceptionally large EIs. Between extremes of EI, where the factors affecting these values could be more clearly discerned, determinants of EI were not so readily apparent. Enteric fermentation overwhelmingly drove emissions on all farms in all regions, 96 - 97% of total GHGs attributable to this source. There are two readily identifiable causes of this difference. Firstly, the livestock systems in this...
study were low input in terms of fertilizers, purchased feeds and mechanization, which in intensive European farming systems account for 7 to 20% of total emissions (Opio et al., 2013; O’Brien et al., 2014; O’Brien et al., 2015). Secondly, emissions from manure management were low as a result of a drier climate, rather than those found in Europe under which manure may comprise 5 to 9% of total emissions (Opio et al., 2013; O’Brien et al., 2014; O’Brien et al., 2015).

Examining the characteristics of farms with low EI farms provides insight into effective strategies to move smallholder farms toward a low carbon future. Enteric CH4 production overwhelmingly drives farm emissions in these systems and, as enteric fermentation is strongly linked to nutrition, intake and productivity, attention must be focused on increasing on-farm output per animal while constraining further increases in enteric CH4 as far as possible. Our results indicate mitigation potential towards improving the productivity on a per animal basis and restructuring the herd in favour of productive females with high(er) milk outputs. This will not only contribute to reduced carbon footprint but will also likely have social and economic advantages such as increasing household incomes.

**Acknowledgements**

This study was funded by the International Fund for Agricultural Development (IFAD) through the research projects “Greening Livestock: Incentive-Based Interventions for Reducing the Climate Impact of Livestock in East Africa” (Grant No. 2000000994) and further supported by the German Federal Ministry for Economic Cooperation and Development (BMZ issued through GIZ) Programme of Climate Smart Livestock (PCSL). The authors further acknowledge the CGIAR Fund Council, Australia (ACIAR), Irish Aid, European Union, IFAD, the Netherlands, New Zealand, UK, USAID and Thailand for funding the CGIAR Research Program on Livestock. The authors appreciate funding from the Biotechnology and Biological Sciences Research Council (BBS/E/C/00010320) and the South African National Research Foundation, NRF Thuthuka Grant No. TTK180419322838.

**References**


THEME 6. PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES

Topic: Changes in Rangeland Property Rights and Land Use in
Central Asia and Western China

User-based pasture management in Kyrgyzstan: Achievements, challenges, and trends

Dörre, A¹; Kasymov, U².

¹ Freie Universität Berlin, Berlin (Germany), Institute of Geographical Sciences, Human Geography; ² Technische Universität Dresden, Dresden (Germany), International Institute Zittau

Key words: institutional change; decentralization; community-based development; central Asia

Abstract

In Kyrgyzstan, a high mountain country in Central Asia, grasslands occupy almost half of the territory. These extensive resources represent the basis for seasonally mobile animal husbandry, which is relevant for both individual households and the national economy. With the dissolution of the Soviet Union and Kyrgyzstan’s transition into a market economy, these formerly state-owned grasslands were parceled out and privatized. Considerable socio-economic distortions and ecological problems occurred during this process. In order to meet such unintended effects, a legal framework for user-based pasture management was established in the course of an institutional learning process. This package of measures corresponded to a decentralization of responsibilities in natural resource management through the stronger involvement of rural communities and, thus, aligns with a central paradigm of the global development discourse at the time. Positive examples can be observed in terms of increasing equal access to grazing land, the empowerment of rural communities, and reduced ecological damage. At the same time, there are local cases of pasture-related ecological problems and overstrained management institutions. In addition to the challenges posed by cross-border pastoral mobility and scrub encroachment on summer pastures, social issues came into focus in current pasture-related interventions in Kyrgyzstan. This paper traces the developments of the regulations and practices of pasture management after 1991, placing an emphasis on the analysis of current trends, achievements, and challenges.

Introduction

Kyrgyzstan’s grasslands form one of the essential sources for securing the livelihood of individual households and the economically important animal husbandry of the country. In order to ensure their long-term preservation and to re-regulate access to, use of, and management approaches towards pasture resources, new regulations were formulated in the course of state independence, which led to ambivalent socioeconomic and ecological effects. Against the background of these results, the experiences and findings of political decision-makers, international donor organizations, and changed global development paradigms, the pasture legislation underwent several changes. Since 2009, a user-based resource management approach has been applied.

Materials and Methods

Study site

The findings are based on the authors’ many years of research experience and the collection of materials on the topics of this paper, a systematic analysis of literature and legal documents, and recently conducted expert interviews with representatives of civil society, the scientific community, and governmental organizations. While previous work of the authors is based on local case studies in different regions of Kyrgyzstan (e.g., Dörre and Borchardt 2012; Dörre 2015; Kasymov and Thiel 2019), the findings presented here refer to the entire country.

Results

In order to be able to assess both the emergence and performance of user-based pasture management in Kyrgyzstan, we outline the most important developments in pasture legislation with regard to resource use and management-related aspects. In our conceptualization of pastoral institutions and their change, we build on North’s understanding of institutions as formal and informal ‘rules of the
game’ (1990: 3). In addition, we extend this notion, and argue in line with Watts that institutions are to be understood as regulated and habituated ‘rules in use’ (2005: 268), which are perpetuated by actions and investments. The diachronic sketch and presentation of the current management approach are followed by an overview of scientific perspectives on this institutional change. Finally, we identify and evaluate current trends and challenges in the pasture sector of Kyrgyzstan.

**Discontinuous development of legal pasture regulations**

The proclamation of Kyrgyzstan’s independence in 1991 was followed by economic decline. The country was forced to embark on a new economic policy course and to find international partners to help address this challenge. It found them in multilateral donor organizations, which tied their support to so-called ‘Washington Consensus’ conditionalities (e.g., deregulation, privatization, and decentralization). During the ‘shock therapy,’ industrial and agricultural enterprises were quickly privatized, along with the technical equipment, livestock, and farmland (Kasymov et al., 2016). Pastures remained state property, but the previously forbidden private use was made possible by means of long-term leases. Comprehensive management responsibilities for seasonal pastures previously held by collective and state farms were decentralized, parcelled out, and allocated to different administrative levels (GRK 1991; PKR 1995; GKR 1999; Crewett 2012; Dörre 2012; Kasymov et al., 2016; Kasymov and Thiel 2019).

The crisis-ridden societal development and the problematic implementation of the new regulations led to complex problems on the ground. Due to limited resources, many pastoralists were not able to maintain long-established, spatiotemporally integrated migration systems. Decreasing seasonal mobility, high livestock concentrations on easily accessible pastures resulted in both increasing degradation and previously non-existent conflict situations between pasture users. At the same time, several remote pastures became increasingly unusable due to underuse and lack of investments in infrastructure such as water pipes, wells, and drift paths. The division of management responsibilities among organizations at different administrative levels led to a patchwork of individualized utilization rights and encouraged the disintegration of proven spatiotemporal migration patterns. At the same time, these organizations were under-equipped in almost every respect and, therefore, overburdened with duties (Shamsiev 2007; Crewett 2012; Kasymov et al., 2016; Kasymov and Thiel 2019). In an attempt to counteract these developments, the government issued a decree based on the advice of various donor organizations and development agencies in 2002. The core contents were the granting of individual usage rights by means of auctions, as well as fragmented management obligations (GKR 2002; Undeland 2005; Shamsiev 2007). Thus, the decree continued to be based on the credos of the primacy of the market as the regulator of social negotiations, privatized resource appropriation, and fragmented management. Steimann (2011) and Dörre (2012; 2015) argue that the adherence to the market principle, the complexity of procurement procedures for pasture usage rights, and fragmented management responsibilities remained the main reasons why the problems mentioned above have not been solved, and have actually worsened.

Against the backdrop of unsatisfactory results, and in the context of the global debate on how to anchor development measures more firmly in civil society, the law ‘On Pastures’ marked a turnaround in 2009. Based on assessments of international organizations, national decision-makers, and, to some extent, local pasture users, as well as experiences from pilot projects on user-based pasture management, the reform was intended to transfer pasture management responsibility to local players. This approach meant an end to the auction-based allocation of private pasture lease rights, and encompassed regulations for the reinvestment of user fees in both ecological pasture rehabilitation and infrastructure maintenance measures in line with local needs. Specifically, it is planned that local pasture users’ associations (PUAs) will establish so-called pasture committees (PCs), which are responsible for the preparation of usage and payment plans, monitoring and sanctioning of violations, and developing schemes for the reinvestment of the generated revenues (GKR 2009; Bussler 2010; Steimann 2011; Dörre 2012; 2015; Kasymov et al., 2016). Looking at these aspects in light of the international development discourse, it becomes clear that the user-based approach can be understood as an implementation of the popular participatory approach in community resource management and rural development. The impression of the legitimacy of the approach is underlined by the fact that in almost every local authority a PC was established shortly after the implementation of the law. However, due to widespread structural equipment deficits, the new regulation also meant an unwelcome burden for many PUAs. This assessment is underscored by the fact that international donor organizations
have, to date, provided substantial funds for user-based pasture management, although the approach itself was already seen as a solution to the problems (IBRD 2013; Jafarova 2013; EI CAMP Alatoo 2020; EI DP 2020).

**Scientific perspectives on institutional change**

These reforms are viewed and assessed very differently in the literature. Kasymov et al., (2016) study the ‘intentionality of institutional change’ to explore how changing beliefs, belief systems, and learning experiences of policymakers affect the development of new pasture-related institutions. Crewett (2015) evaluates the concrete implementation of formal regulations in local settings. She emphasizes the importance of interest-led street-level bureaucrats who, depending on their authority, act as more or less effective agents of change. As a result, pasture use and management regimes are locally specific outcomes of negotiation processes of unequally powerful actors. Isaeva and Shigaeva (2017) highlight the path dependency of institutional change, emphasizing that the Soviet knowledge, management, and use practices internalized by individual actors are reflected in the de facto regimes and, thus, have a long-term impact. According to Dörre, a fundamentally critical reading of the reforms is to interpret the commodification of pasture land, the withdrawal of the state from administrative tasks, and, finally, the delegation of resource management costs to the local level as an expression of neoliberal, informally inflected austerity policies (Dörre 2015). Dörre (2012; 2015) also criticizes the reform from 2009 for being based on an externally developed blueprint model and an apolitical understanding of the community that ignores local power asymmetries and unequal needs and capabilities. Shigaeva et al., (2016) use examples to show that the supposedly participatory character of the user-based management approach is highly controversial at the local level. To some extent, top-down initiated measures, management bodies, and procedures are seen as instruments of paternalism and agencies of resource control and exclusion of certain groups from decision-making processes. Furthermore, Kasymov and Thiel (2019) pose questions about the significance of interactions of formal and informal institutions for the ecological degradation of pastures until 2009 and how subsequent reforms of the formal framework have been changing power relations among pasture users, influencing pasture management and use regimes on the ground. A local case study shows how the formal regulations in force until 2009 promoted ‘grandfathering rule,’ in the sense of “first in time, first in right” (Dumon et al., 2019), i.e., how powerful individual pasture users holding long-term usage rights put their own interests first and, thus, limit the resource appropriation options of their competitors. The authors argue that with the 2009 reform, the balance has been shifting in favor of economically weaker pasture users, contributing to increase their pastoral mobility. It has become more likely that pasture management and use will become socially, ecologically, and economically more sustainable in the future.

**Current trends and challenges**

In our opinion, the current situation seems to support the arguments presented by Kasymov and Thiel (2019). User-based pasture management is increasingly finding legitimacy with local communities and is gradually achieving desired results in terms of growing pasture mobility; a greater participation of local stakeholders in both pasture management-related decision-making and the economic potentials of the cooperation in resource use; a more effective monitoring and sanctioning of usage practices; and a decrease in conflicts within user communities. The continued support of local management structures by international organizations through capacity building measures contributes to these improvements. These measures also address long-standing problems of insufficient information generation and the tenacious exchange of knowledge within the PUAs. However, the positive impression is clouded by the observation of various experts that trained pasture managers are increasingly switching to better paid jobs – so that one can speak of an inner-Kyrgyz brain drain – to the detriment of user-based pasture management (EI CAMP Alatoo 2020; EI DP 2020; EI MSRI 2020). From an institutional and legal perspective, two developments may have strong effects in the long-term. In order to increase the collection of user fees by PCs, which had previously been considered inadequate due to a lack of transparency and effectiveness, the new state budget code from 2016 introduced the rule that pasture fees are to be paid to the respective local authority instead of to the PC (GKR 2016). This enables the administration to invest directly in pasture-related measures. However, the obstruction of the work of the PCs resulting from the delayed transfer of funds has been criticized (EI CAMP Alatoo 2020; EI DP 2020; EI MSRI 2020). The second development is the extension of the user-based management approach to pastures of the forest fund category, which were managed until 2018 solely by state-owned forest enterprises. This puts an end to the long-standing practice of different
management approaches for pastures of different land categories, which had created a great deal of confusion for pasture users. However, there is no guarantee that the cooperation between PUAs and state-owned forest enterprises will run smoothly and free of conflict, as oftentimes different interests are pursued by the involved players (GKR 2018; El CAMP Alatoo 2020; CAMP Alatoo 2020).

The questions of how to regulate cross-border pastoral mobility and the use of pastures by foreign citizens remain largely unsolved. In this respect, the law refers to bilateral governmental regulations, which to our knowledge do not exist (GKR 2009; Ibraimova et al., 2015; Murzakulova and Mestre 2016). While Dörre (2016) already emphasized the problematic connection between the new state borders in Central Asia and pasture mobility, Kurmanalieva and Crewett (2019) show in a detailed case study how conflicting interpretations of historical usage practices, notions of resource usage as a zero-sum game, and institutional ambiguities lead to conflict situations that repeatedly lead to open violence, but in individual cases also lead to pragmatic bottom-up solutions.

From an ecological point of view, the increasing scrub encroachment (Caragana) of summer pastures has become a serious problem in recent years (DP 2020; EI DP 2020). According to experts, the reason for this development is that these plants are no longer used as fuel and construction material for corrals. Additionally, the phenomenon is an unintended effect of the decrease in goat grazing. At present, efforts are being made to deal with this problem through experiments with heavy clearing technology and chemical solutions such as the controversial application of glyphosate (Nurmanbetova 2017; EI DP 2020).

To date, many development organizations implement various projects that address different aspects of pasture use and management. One of the recent focus areas is child and youth education and awareness building pursued by the ‘Development Centers on Jailoo’ project, which is supported by international organizations and has been implemented by national partners since 2014. It is active in all seven provinces of Kyrgyzstan. The background of the project is the observation that many children and adolescents of pastoral households have only limited access to education and learning opportunities during the summer grazing period, and, therefore, suffer long-term professional disadvantages. Under the motto ‘Gleams of hope,’ cultural, ecological, social, and scientific issues are taught free of charge and at an age-appropriate level. This knowledge can be applied in the short-term in schools and in the long-term in the children’s professional lives. By 2019, the program is said to have reached over 15,000 children and nearly 6,000 parents (EI DCJ 2020).

Conclusion

The results reveal three key dyads. First, the shifting pasture management-related institutions are to be understood both as proactive attempts to shape human-environment relations in times of social change and as reactive measures against unintended developments. Second, it becomes clear from situated pasture management regimes that the ‘rules in use’ are not a one-to-one translation of legal provisions but rather correspond to a contingent interplay between formal and informal institutional aspects that depend on local socio-ecological conditions. Third, it is evident that Kyrgyzstan’s pastoral sector is still changing and is characterized by challenges for which pragmatic solutions are still being sought. Kyrgyzstan’s pastures are increasingly being treated as a socially embedded and multidimensional issue, rather than reduced to the problem of finding an adequate institutional framing. This observation strengthens the hope for a stronger focus on pastures not only as an economically relevant natural resource and ecosystem service provider, but also as a socially, culturally, ecologically, and economically important component of the society of this high mountain country.

References


Crewett, W. 2015. Introducing Decentralized Pasture Governance in Kyrgyzstan: Designing


EI MSRI 2020. Expert interview with representatives of the Mountain Societies Research Institute of the Graduate School of Development of the University of Central Asia. 28 February 2020, Bishkek.


Jafarova, A. 2013. World Bank to Allocate $90 million to Kyrgyzstan for Pasture Development. Available


The role of community cooperative institutions in addressing livelihood challenges in the process of urbanization of pastoral regions in China

Gongbu, Z.1 and Zhang, Z.2

1 Southwestern University of Finance and Economics, Chengdu, China.
2 Zhejiang University, China.

Key words: Urbanization; pastoral area; rangeland management; herder cooperative; grazing quota system

Abstract: In contrast to the agricultural settings, urbanization processes in the pastoral regions of China are primarily driven by long-term influences of ecological conservation and the provision of social services. Consequently, many herders who have migrated into nearby, secondary urban centres depend on resources from the pastoral regions to support their livelihood, forming complex patterns of rural-urban linkages. While current literature has discussed the processes of herder out-migration and their implications on rural and urban livelihood development, few have examined the linkages between herders living in the pastoral regions and those who have out-migrated to the urban areas their importance in rural livelihood transformation. Innovative community cooperative institutions developed by pastoral communities from the Tibetan Plateau may be able to offer a new perspective and insight on how to better maintain rural-urban linkages in the processes of urbanisation in the pastoral regions. We will present two comparative villages where GD Village applied cooperative community institutions to address livelihood challenges. In ZR Village, most out-migrated herders fully decoupled themselves from rangeland resources and only depend on income sources from urban regions through individual bases to support their livelihoods. This study demonstrates that the cooperative community institution is more effective in addressing the livelihood challenges in urbanisation. While current studies recommend increasing government subsidy, providing vocational training and social insurances that help herders better adapt to urban livelihoods, we argue that rangeland management and community economic cooperation through innovative institutions are needed to facilitate mobilities of livestock resources and herder population. Only then maybe the livelihood challenges that migrated herders face will be addressed effectively.

Introduction

Urbanization of pastoral regions is one of the great socio-economic transformations that has increased mobility of herder populations in China and restructured rural livelihoods (Bao and Shi, 2020; Gongbu et al., 2021). Differing from urbanization in the agricultural regions of China where population out-migration are voluntary movements induced by marketization and economic opportunities (Jin and Li, 2019), the urbanization processes in the pastoral regions are driven by long-term interactive influences of multiple policies, including rangeland ecological conservation policies (caoyuan shengtai jianshe), rural school consolidation policy (chedian Bingxiao), rangeland institutional reforms (caochang zhidu gaige) and rural poverty alleviation programs (tuoping gongjian zhengce) (Washul, 2018; Bao and Shi, 2020).

Particularly, ecological conservation programs including “retired grazing to restore grassland” (tuimu huancao) and “ecological migration program (Shengtai Yiming)” are among major strategies that encouraged pastoral households to be resettled in townships and county seats (Ptackova, 2011; Du et al., 2014; Jiumaocuo and Wang, 2016). Therefore, herder out-migration in China’s pastoral regions has been driven by top-down policy interventions, integration of rural pastoral regions into marketization and herder voluntary movements (Wang and Xiu, 2014; Jin and Li, 2019).

In this process, two major out-migration patterns have emerged to form complex rural-urban linkages. First, the whole pastoral families have been resettled in urban areas. However, many of them could not find viable income sources in urban
regions, so they continued relying on resources from the pastoral areas, including a collection of caterpillar fungus and livestock production to support their urban livelihoods. In the second pattern, family members live separately in urban and pastoral regions; elders accompany their children to live in the urban areas while young family members stay in the pastoral areas to maintain livestock production and support their livelihoods. Therefore, unlike agricultural regions where out-migrants tend to explore alternative income sources to support their rural homes, out-migrated herders depend on rural rangeland resources to support their livelihoods in the urban regions.

Some studies argue that rural livelihood transformation due to urbanization is a long-term process as herders living in both urban and rural regions depend on complex linkages between these regions to access markets and rangeland resources sustaining livelihoods (Huntsinger et al., 2010; Eriksson, 2011; Du, 2014; Fan et al., 2015; Zhang, 2020). Therefore, we need to frame urbanization in the pastoral regions to see the rural and urban as a coupled system. Based on the social-ecological features of pastoral regions, we have developed three conceptual movement types - livestock mobility, herder mobility and resource mobility - which could maintain rural-urban linkages and address herder livelihood changes under accelerated urbanization.

First, livestock mobility is a major characteristic of traditional pastoral systems globally, a production and coping strategy that facilitates greater levels of livestock production, use of shared labour, escape from localized drought or cold, access to landscape heterogeneity, and use of widely dispersed water sources (Behnke and Scoones 1993; Li and Huntsinger 2011; Kratli, 2019). Second, the improved infrastructures in China’s rural regions and the increasing commodification and extension of capitalist systems of production in rural regions have diversified the use of and the economic values of the rangelands (Cleaver, 2012; Thornton and Manasfi, 2010; Chaudhury et al., 2017), increasing mobility of herders and resources between rural and urban regions. Third, under current socio-economic changes, rangelands support livestock production and provide resources for the development of ecotourism, collection of lucrative medicinal herbs such as caterpillar fungus, and rental of grazing lands to earn fees (Gongbuzeren et al., 2018). Particularly, the development of the rural tourism industry in the pastoral regions of the Tibetan Plateau in the recent decade has created consumption markets for rural livestock products and cultural artefacts. Therefore, migrated herders continuously move between urban and rural regions to access resources from the rangeland to support their livelihood while exploring other livelihood options in the urban regions (Jin and Li, 2019; Zhang, 2020; Bao and Shi, 2020). In addition, there are increasing cultural industries and businesses such as Tibetan restaurants and cultural performance centres in the urban regions. Pastoral family members move into urban regions for small-scale business opportunities or temporary employment in these culturally-related entities. Therefore, even though livestock production and other rangeland resources are the main sources of livelihood for herders who stay in pastoral regions, they also try to participate in new markets for other income opportunities. Given these, both groups of herders, either living in rural or urban regions, constantly move between these regions to access resources, thus forming complex patterns of herder and resource mobilities.

We argue that mobility of livestock, herders and resources are key features of rural-urban linkages in the processes of urbanization in the pastoral regions for addressing livelihood development challenges for herders. However, maintaining all three mobilities creates critical challenges for rangeland management institutions and tenure regimes. It requires institutions operating across multiple scales to rebuild cooperation and collective action among the herders in pastoral rural-urban linkages.

In this paper, we present comparative case studies from Yushu Prefecture of Qinghai Province to illustrate how pastoral communities on the Tibetan Plateau have developed innovative rangeland institutions and ask what perspectives these cases present to advance our understanding of the roles of cooperative community institutions in building rural-urban linkages.

Materials and Methods

Study Site

In addressing the research questions, we present comparative case studies from Yushu Prefecture of Qinghai Province (i.e., GD Village and ZR Village) that underwent fundamental institutional changes. We conducted our fieldwork from June-September of 2018 and 2019, carrying out semi-structured interviews with total of 55 out-migrated households in ZR Village and 59 households in GD Village. The interviews focused on basic household information, including demographic data, household assets and livestock numbers, detailed household income and expenditures, household livelihood capitals, rangeland
management systems, access to credit loan and livestock insurances, and livelihood strategies of herders’ perception of the rangeland ecosystem changes. In addition, we applied a Sustainable Livelihood Development framework to understand how with and without community cooperative institutions facilitate herders’ access to livelihood capitals and livelihood strategies, and how these differences lead to livelihood outcomes.

**Results**

After the Government of China started to promote the Rangeland Household Contract System in late 1990s, within a couple of years, all households began building fences around their contracted individual grazing parcels. Since early 2000 and especially after 2010, many pastoral households from GD village have been resettled in Yushu City. Despite this, herders who have out-migrated into Yushu City and those who remained in the pastoral regions collectively started a herder cooperative in 2010, that encouraged all herders in the village to participate. Using this as the platform, after years of negotiation, in 2017, herders in the GD Village agreed to remove their fences, which restored the collective community management of rangeland, allowing four-season livestock mobility practices while allocating the right of each household to collect caterpillar fungus (a lucrative medicinal herb that only grows in certain areas of GD village rangelands) from the community rangeland area. Through cooperative management, the herder community established small-scale businesses, such as supermarkets, while purchasing milk and butter from local herders, which diversified local incomes and provided employment. This management system helped out-migrated herders to access resources from the pastoral regions as well as provide the herders access to markets. Comparatively, ZR Village had a very different management system; they contracted their rangelands into four groups, and each group collectively used their rangelands without fences demarcating boundaries even though rangeland portions had been contracted to individual households. Caterpillar fungus only grows in the pastoral areas of group numbers 3 and 4 at higher elevations. After the rangeland contract system, herders from groups 1 and 2 have to pay to collect caterpillar fungus in the other group’s pastures. This village is very near to Yushu City, the capital of Yushu Prefecture. Therefore, since 1990s, families from this ZR village gradually moved to be resettled in Yushu City. However, out-migrated pastoral families do not have formal cooperation on managing resources and business entities among the out-migrated herders and those village herders. They still live in the pastoral regions. Out-migrated herders participate individually in the market economy and have to pay to collect caterpillar fungus in their home area.

Both GD and ZR villages have herders have been resettled in the Yushu City, but their cooperative management institutions are very different. GD Village represents a case where out-migrated herders maintained close cooperation with herders living in rural areas through complex patterns of rural-urban linkages to maintain access to rangeland resources and markets. Comparatively, ZR Village represents a case where out-migrated herders do not have any formal cooperation and linkages with rural herders, and they participate as individuals in urban livelihoods and markets.

First, the analyses of livelihood capital shows that while both villages share similar levels of physical, human and financial capitals, herders in GD Village have higher levels of social and natural capital. Second, for on livelihood strategies, the level of livelihood diversification index shows that average household livelihood diversification index in GD Village is 3.71, much higher than ZR Village (1.53). Third, the different patterns of rural-urban linkages have direct implications for herders’ livelihood strategies. Out-migrated herders in GD Village have two livelihood strategies; 39% of interviewed households mainly depend on rangeland resources while having some income from urban sources, while 61% of household samples mainly depend on income sources from urban areas, though they also depend on support from rangeland resources. Comparatively, in ZD Village, 71% of the interviewed households fully decoupled their income sources from rangeland resources, and tried to engage with urban livelihoods and depend on government subsidies. Given these differences, out-migrated households in GD Village have higher levels of net-income than ZR Village. Based on this, we argue that the community cooperative institutions are more effective in addressing livelihood challenges that out-migrated herders encounter in the process of urbanisation.

Regarding community cooperative institutions, GD Village has applied custom-based and market-based institutions at both individual scale and community scales to govern rangeland resources.

First, the community cooperative institutions developed innovative systems such as clarified entitlement of collecting caterpillar fungus and stock shares from community cooperative businesses to protect individual benefits and rights at the household scale. This guaranteed individual benefits and rights of the herders living in both rural and urban regions, and facilitated resource
and herder mobility.

Second, the community cooperative business entity facilitated resource mobility between rural and urban regions, and increased sources of income for all herders.

Third, through clarification of individual pasture rights, GD Village is able to restore or maintain community collective use of rangelands with seasonal livestock mobility to increase livestock production efficiency, benefitting all herders who keep livestock. Given this, we believe these innovative institutions in GD Village show the need for institutions to operate at multiple scales to maintain rural-urban linkages.

Conclusions

While the Chinese government has promoted market-based institutions to facilitate the rangeland transfer system based on individual needs, our studies find that communities are developing more innovative rangeland institutions that may offer critical insights and contribute to the issues mentioned previously. Community cooperative institutions are one management system that could facilitate the three types of mobilities. This management system protected individual rights and benefits through distribution of bundles of entitlements to resources and market access. The pastoral communities have applied hybrids of informal customary rules and formal market-based institutions to restore community cooperation over management of rangeland resource and participation in marketisation while redefining networks and distribution of benefits and rights among individual herders. We believe that these self-reorganised institutional innovations provide an interesting perspective on how pastoral communities have evolved through urbanisation processes, rebuilding institutions that could maintain or restore livestock mobility, herder mobility and resource mobility between herders living in rural regions and those out-migrating to urban regions.

Acknowledgements

This paper was supported by Natural Science Foundation of China Youth Project (71703126), the Fundamental Research Funds for the Central Universities (JBK2101035), and the European Research Council (ERC) Advanced Grant Project PASTRES project (Pastoralism, Uncertainty & Resilience: Global Lessons from the Margins; www.pastres.org). We also want to thank Professor Carol Kerven and Li Wenjun for their review and comments on the paper. And we want to express our deepest gratitude to the local guide and herders who dedicated time and effort to our fieldwork.

References


Obstacles to the revival of mobile grazing systems in Kazakhstan

Robinson, S.1; Bozayeva, J.3; Mukhamedova, N.1; Djanibekov, N.2; Oshkhbayev, D.4; Petrick, M.1

1Justus Liebig University, Giessen; 2Leibniz Institute of Agricultural Development in Transition Economies (IAMO); 3FAO, Astana; 4Talap Kazakhstan

Key words: pastoral tenure; livestock production; land reform; fodder

Abstract
Livestock mobility was an essential characteristic of Kazakh livestock production systems, allowing animals to take advantage of spatial and temporal variability in climate and vegetation, optimising forage intake over the year. These systems broke down following the end of the Soviet Union. In this paper we examine the extent and determinants of the recovery of mobile livestock husbandry in south-eastern Kazakhstan, using surveys and semi-structured interviews with livestock farmers and rural households (holding livestock but not registered as farms). We find positive relationships between livestock holding size and probability of mobility. Winter pastures are particularly important for large farms, with households and smaller farms more dependent on supplementary fodder. The major formal property right over pasture is the long-term leasehold, allocated by auction and associated with significant transaction costs. Leasehold markets function poorly, so farms use a combination of leasing, subleasing and short-term contracts with local authorities to assemble the pastoral resources they need. Few farmers conduct more than a simplified summer-winter migration, whilst around 30% of farms and 70% of households (which own the bulk of livestock) are entirely sedentary, staying on over-used village pastures all year round. Many of these producers express a desire for improved pasture access. The 2017 Law on Pastures introduced district-level pasture use planning, with promotion of mobility and allocation of remote pastures to those with poor access. But the Law does not include new land tenure mechanisms appropriate for small producers (owning few livestock and without leaseholds) which can be employed to realise this goal. Moreover, most pastures are already leased. We discuss options for grazing system management which may simultaneously increase the economic contribution of pastures, improve their condition and reduce rural inequalities created by disparities in access to resources.

Introduction
Kazakh livestock production systems traditionally used mobility to take advantage of spatial and temporal variability in vegetation and climate, optimising forage intake over the year. The Soviets built on these systems, allocating separate pastures for summer, winter and autumn/spring (Robinson et al., 2016). In the 1990s migratory systems broke down, but have re-emerged in recent years, with benefits for pasture condition, animal weight gain and farm profitability (Alimaev et al., 2008, Issayeva and Bakhralinova 2020, Kerven et al., 2004, 2016, Mirzabaev et al., 2016). Yet many pastures remain underused, whilst those around settlements are often degraded (Alimaev et al., 2008, 2015). The studies cited here, which focussed on sheep husbandry, suggest that mobility can largely be predicted by farm scale and that collective herding institutions have not created the economies of scale required for small herders to reach distant pastures. We ask whether the same patterns apply to cattle production in a vertical transhumant system, examining the extent to which different producers are able to follow migratory systems and the land access arrangements which they use to do so. The 2017 Law on Pastures was designed to improve pasture management through greater use of seasonal pastures. Whether the provisions of this law can be implemented given underlying land tenure mechanisms appropriate for small producers (owning few livestock and without leaseholds) which can be employed to realise this goal. Moreover, most pastures are already leased. We discuss options for grazing system management which may simultaneously increase the economic contribution of pastures, improve their condition and reduce rural inequalities created by disparities in access to resources.

Materials and Methods
Study site
The study site included the eastern half of Enbekshikazakh district and Raiymbek district (Figure 1), which host migratory routes, many of which have existed for centuries, between alpine summer pastures and wintering areas on south-facing slopes or plains (Ferret 2018). A survey on
livestock production systems was applied to 200 registered individual farms and 50 households (holding livestock but not eligible for long term land leases). Farms were selected from lists using two-stage cluster sampling and households by random visit in the sampled villages. The relative weights of households and farms in overall livestock inventories are not reflected in the sample, so we present this using district statistics. For analysis, farms were split into four quartiles on the basis of cattle ownership. In-depth interviews were conducted with a subset of twenty livestock producers from the survey, district officials; staff of the provincial Land Resources Department, an employee of the Institute of Livestock and Fodder who contributed to the 2017 law, and the director of an NGO piloting approaches for its implementation.

Results

Livestock ownership

Livestock ownership follows a lognormal distribution, with many producers owning small numbers of animals and a small number having large herds (Table 1). Ownership of other stock (for example sheep and goats) correlates strongly with cattle holdings, as few farms specialise in a single species (Table 1). Mean cattle ownership amongst households is similar to that of smaller registered farms, but the total cattle population held in households is much larger.

<table>
<thead>
<tr>
<th>Variable means (survey sample)</th>
<th>Household (HH) or farm cattle ownership quartile (Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HH</td>
</tr>
<tr>
<td>N</td>
<td>50</td>
</tr>
<tr>
<td>Cattle (head) †</td>
<td>9</td>
</tr>
<tr>
<td>Cattle (head, range)</td>
<td>1-39</td>
</tr>
<tr>
<td>Sheep &amp; goats (head)</td>
<td>20</td>
</tr>
<tr>
<td>Cropland (ha)</td>
<td>1.2</td>
</tr>
<tr>
<td>Roughage (kg/head/yr)*</td>
<td>1709</td>
</tr>
<tr>
<td>Concentrate (kg/head/yr)*</td>
<td>412</td>
</tr>
<tr>
<td>Total cattle population††</td>
<td>72,577</td>
</tr>
</tbody>
</table>

Source: 2018 farm survey; † Variable used to create quartile; * head of cattle; †† In the entire study site, district statistics

Mobility and herd size

Herd size is a major determinant of mobility, with larger producers more likely to move at least once over the year (Fig. 2a). Whilst all mobile producers use remote pastures in summer, a much smaller proportion use such pastures in winter, with most returning to village grazing areas in that season (Fig. 2b).
One reason for this could be that, in winter pastures, capital investments in houses and barns are required (Kerven et al., 2016). These outlying bases are located in areas where climatic conditions and vegetation are suitable for winter grazing (Ferret 2018). Located on average around 10km from settlements (although some are much further away), stock may be based there for three seasons, or all year around in a few cases. Summer pastures are on average 45km (and up to 200km) from settlements and here temporary accommodation such as yurts can be used. Only 10% of farms move three times, using autumn/spring pastures in addition to summer and winter areas, following Kazakh tradition and Soviet scientific pasture management norms (Figure 2a). Differences in pasture access have consequences for winter fodder provision, and may explain the negative relationship between cattle ownership and annual weight of roughage provided per head of cattle by farms (Table 1). Households provide on average 2.5 times more concentrate per head than farms and purchase a larger proportion of the fodder they provide, due to poorer access to arable land.

**Property rights**

Differences in pasture access have consequences for winter fodder provision, and may explain the negative relationship between cattle ownership and annual weight of roughage provided per head of cattle by farms (Table 1). Households provide on average 2.5 times more concentrate per head than farms and purchase a larger proportion of the fodder they provide, due to poorer access to arable land.

![Figure 2: Indicators of seasonal pasture use by households (HH) and farms (Q1-Q4)](image2)

The major formal mode of agricultural land access in Kazakhstan is the 49-year lease from the state. Some pastures accessed in this way represent land shares received through restructuring in the mid-1990s or by application just afterwards. However, such leases are currently allocated by auction, which all but excludes smallholders due to conditions for participation, bureaucratic hurdles, and cost. Survey data suggest that long-term lease of state lands is the most frequent mode of access, but by no means the only one (Table 2). Households and smaller farmers are most likely to sublease from other farmers, although this is illegal, whilst short-term lease of Forestry Department land in summer is common amongst larger farmers. As-yet unleased ‘state reserve land’ is used informally and some parts of this have been set aside for common use, particularly in Embekshikazakh district. In winter, 49-year leaseholds dominate: as the need for housing in these areas increases the importance of tenure security, whilst forest and reserve lands are rare in wintering areas.

![Figure 3: Pastureland in Raiymbek district](image3)

*Source:* Raiymbek district statistical department. Forest Department and protected areas are predominantly pasture.

The major formal mode of agricultural land access in Kazakhstan is the 49-year lease from the state. Some pastures accessed in this way represent land shares received through restructuring in the mid-1990s or by application just afterwards. However, such leases are currently allocated by auction, which all but excludes smallholders due to conditions for participation, bureaucratic hurdles, and cost. Survey data suggest that long-term lease of state lands is the most frequent mode of access, but by no means the only one (Table 2). Households and smaller farmers are most likely to sublease from other farmers, although this is illegal, whilst short-term lease of Forestry Department land in summer is common amongst larger farmers. As-yet unleased ‘state reserve land’ is used informally and some parts of this have been set aside for common use, particularly in Embekshikazakh district. In winter, 49-year leaseholds dominate: as the need for housing in these areas increases the importance of tenure security, whilst forest and reserve lands are rare in wintering areas.
Table 2: Modes of remote pasture access by household and cattle ownership quartile (Q)

<table>
<thead>
<tr>
<th>Variable</th>
<th>HH</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>All farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>50</td>
<td>56</td>
<td>49</td>
<td>45</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Leases state pastures</td>
<td>8%</td>
<td>21%</td>
<td>35%</td>
<td>38%</td>
<td>38%</td>
<td>33%</td>
</tr>
<tr>
<td>Subleases pasture</td>
<td>12%</td>
<td>16%</td>
<td>12%</td>
<td>7%</td>
<td>4%</td>
<td>10%</td>
</tr>
<tr>
<td>Uses state reserve land / common reserve areas</td>
<td>6%</td>
<td>9%</td>
<td>8%</td>
<td>9%</td>
<td>26%</td>
<td>12%</td>
</tr>
<tr>
<td>Leases from forest department</td>
<td>2%</td>
<td>11%</td>
<td>8%</td>
<td>31%</td>
<td>24%</td>
<td>18%</td>
</tr>
<tr>
<td>Leases state pastures</td>
<td>0%</td>
<td>13%</td>
<td>10%</td>
<td>29%</td>
<td>42%</td>
<td>23%</td>
</tr>
<tr>
<td>Subleases pasture</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>Uses state reserve land / common reserve areas</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
<td>4%</td>
<td>18%</td>
<td>7%</td>
</tr>
<tr>
<td>Leases from forest department</td>
<td>4%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>4%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Source: 2018 farm survey. Difference with 100% is made up by farms and households not using remote pastures.

In Raiymbek district, of lands available for 49-year leasehold (sum of state reserve and already-leased lands in Figure 3), 85% have already been leased to producers and the remainder is state reserve land, much of which is poorly accessible. Six percent of lands presented in Fig. 3 are designated as village land, available for common use (the equivalent figure is 12% nationally). It is here that sedentary households and farms graze their animals. In our sample, 66% of cattle held in households and 15% of those in farms are sedentary (with figures similar for other stock). Cattle held in households comprise 60% of the total, with farms accounting for 35% (Table 1). Application of our estimates of sedentariness rates in farms and households (Figure 2) to these numbers suggests that about half of all cattle in the study area are held on village lands all year round. Yet, whilst some owners prefer to keep livestock at home, especially dairy animals, almost 40% of households and 20% of farms in Q1 desire greater access to summer pasture. Reasons given by respondents for lack of access to this resource included availability (already leased), physical barriers, and (for households) lack of legal rights. Costs of herding and pasture lease were considered less important.

**The 2017 Law on Pastures: Implications for grazing access**

The 2017 pasture law was introduced to resolve the kinds of misbalances in grazing pressure documented in this paper (Alimaaev et al., 2015). It introduces the concept of district-level pasture use planning and the establishment of pasture users’ associations (PUAs). Plans should include cadastral boundaries, infrastructure, water sources, a livestock migration schedule, and indicate ‘allocation’ of distant pastures to livestock owners lacking pasture. However, the Law does not specify new land tenure mechanisms. The reference remains the 2003 Land Code, of which the most commonly employed modality of access is the 49-year leasehold, allocated through procedures unrelated to the type of ecosystem-level pasture management which the law attempts to instate. Where land is already leased, there are few options for pasture use planning. Large areas of leased pasture are unused or underused (Ministry of Agriculture of the Republic of Kazakhstan 2018), yet it is difficult to transfer contracts between farmers or even return land to districts for re-allocation. The national government plans imminent expropriation of ‘inefficiently’ used land – a process perhaps supported by clauses in the 2017 law allowing expropriation upon absence of grazing for two years, or at grazing pressures less than 20% of the maximum permissible. This process, if it can be accomplished, may free up new lands but also risks arbitrary land seizures. Expropriated lands may be re-allocated by auction, and thus unlikely to be available to small producers. Unleased state reserve land (Figure 3) can be used informally, but these areas are often distant from settlements and poorly served by infrastructure. The allocation of reserve land for common use, as observed in Enbekshikazakh district, could be one solution if applied to newly expropriated lands. But the overall rate of seasonal mobility amongst farms and households in this district is no higher than in Raiymbek and, as elsewhere, this land is used predominantly by large producers (Table 2). Possible explanations include the limited area of this land in relation to demand (mentioned by respondents), or lack of collective herding institutions to enable their use by smaller producers. Such systems do exist on
village pastures, where producers pool animals and herd on a rota basis. In summer pasture, self-herding or hiring of professional shepherds is more common, but around 30% of mobile respondents share herding in some way.

**Discussion**

Economics of scale and ability to access formal land rights mean that mobile livestock husbandry is most common amongst larger farms, which are thus less reliant on winter supplements than small producers. Collective herding institutions and commonly used remote pastures do exist, but are not sufficient to promote mobility amongst households and small farms. Planned re-allocation of underused leased pasture may improve availability, but unless modalities of access other than leasehold auction can be employed, it is unlikely that small producers will benefit. Measures to improve pasture management could include: increasing fluidity of leasing markets through easier transfer or division; legalisation of subleasing; linking of leasehold allocation procedures to pasture use planning; improving roads to and infrastructure in pastures, and setting aside a greater proportion of reserve land for non-leaseholders. The PUAs foreseen in the Law on Pastures could build on existing institutions to support small producers to access pasture. Decentralised planning processes should support identification of locally appropriate solutions.

**Acknowledgements**

This study draws on two projects: “Revitalising animal husbandry in Central Asia: A five-country analysis (ANICANET)” ([www.iamo.de/anicanet](http://www.iamo.de/anicanet)), funded by the German Federal Ministry of Education and Research (BMBF); and “SDGnexus Network” ([www.uni-giessen.de/fbz/zentren/zen/sdgnexus/network](http://www.uni-giessen.de/fbz/zentren/zen/sdgnexus/network)) supported by the Federal Ministry for Economic Cooperation (BMZ) through the German Academic Exchange Service (DAAD). We thank Carol Kerven for reviewing the manuscript.

**References**


THEME 7: CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/ GRASSLANDS

Topic; Participatory Socio-ecological Observatories for Sustainable Rangeland Development
Drylands Participatory Observatories: a new socio-ecological technology to co-produce knowledge and science to develop policies for sustainable development

Martínez-Tagüeña, N; Huber-Sannwald, E; Espejel, I; Reyes Gómez, V.M; Lucatello, S; and C.L. Lauterio Martínez

Key words: co-production of knowledge; social innovation; sustainable development; governance

Abstract
Drylands Participatory Observatories are spaces to collectively produce, compile and exchange knowledge that bring together interested stakeholders of a particular socio-ecological system to jointly understand and share how to put into practice concepts of resilience, adaptation and transformation in project co-design and co-development, and in participative policy making, to achieve sustainability. They are developed as long-term projects that can endure based on local participation and their utility that emanates from the peoples’ needs and interests. Rural stakeholders, such as pastoralists, are and will be the key players and decision-makers at the local scale, and their needs and knowledge are fundamental for regional, national and international policy-making. The development of policy for sustainable development is a daunting task as it encompasses the needs and interests of people, socio-economic and climate change problems, the actors and the resulting programs, which must be accompanied by indicators and models to monitor, evaluate and compare the progress in sustainable development through time. These indicators must integrate social, cultural, economic, environmental and political aspects, and should be focused on the achievement of a sustainable development where people have freedom of choice to experience a full life according to their own notion of wellbeing. This paper provides examples from five case studies with an emphasis on two rangelands in Northern Mexico where the Participatory Observatories have created innovative ways to monitor sustainable development over the long term.

Introduction
Human population continues to rise and socioeconomic activities in dryland regions have enormous environmental consequences on the functional integrity of their socio-ecological systems (SES). Long-term mitigation efforts to combat desertification and restore drylands are challenging and need multiple stakeholders’ alliances (Reynolds et al., 2007). Bottom-up governance approaches are essential to achieve adaptive livelihoods that build on social and natural capital as the essential pillars of sustainable dryland life-support systems (Chapin et al., 2009). These types of partnerships are essential to accomplish the Sustainable Development Agenda of the United Nations (SDG 17), which aims to implement climate actions (SDG 13), combat desertification (SDG 15), and protect the biosphere’s terrestrial and marine biodiversity (SDG 15 and 14, respectively) as fundamental goals to eradicate poverty (SDG 1), achieve gender equality (SDG 5), food security (SDG 2), health (SDG 3), economic prosperity (SDG 8), sanitation and water quality/quantity (SDG 6), among others (https://www.un.org/sustainabledevelopment/sustainable-development-goals/).

Therefore, academic and government institutions from Latin America, Northern Africa and Southern Europe developed the Agadir Platform for cooperation and collaboration. As a focal network of this platform, Mexico established the first national/international network called ‘The International Network for the Sustainability of Drylands (RISZA)’. Its purpose is it to co-generate useful knowledge with local, national, regional and transatlantic transdisciplinary research alliances including academics, government representatives, civil society members, NGOs, and indigenous groups, for integrated drylands
assessments; for socio-ecological conservation, restoration, management and development projects; and for guiding adaptive management and policy development (Huber-Sannwald et al., 2020). Thus, this network promotes intercultural dialogue in equity and respect with an overall mission to strengthen higher education, improve communication, and co-produced knowledge necessary for policy making. RISZA has organized and participated in various events, workshops, outreach and project development (https://risza.mx/inicio).

RISZA’s members identified relevant dryland topics as priority themes, including pastoralism, water, mining, livestock production, agriculture, food security, health, migration, social innovation and governance. Also, an operational framework was designed with four main concepts: Transdisciplinarity, Socio-ecological System, Interculturality and Governance (Huber-Sannwald et al., 2020). Transdisciplinary studies go beyond scientific knowledge to weave other knowledge systems from all the actors involved in a SES through equitable and respectful dialogues to develop social innovations and better governance. One important project that emanates from this operational framework is the creation of ‘Drylands Participatory Observatories’ (DPO) as spaces to collectively produce, compile and exchange knowledge bringing together interested stakeholders of a particular SES to jointly understand how to put into practice resilience, adaptation and transformation in project co-design and co-development, and in participative policy making, to achieve sustainability. The UN SDGs need new ways of integrating social science with technology development (European Union 2017).

Drylands Participatory Observatories: a new socio-ecological technology

Today observatories are very popular to study and learn certain themes of public interest. The majority of them provide forecasts, warnings, and information about particular hazards based on scientific understanding of processes and make this data available to local communities (ie. https://www.usgs.gov/natural-hazards/volcano-hazards). Citizens’ Observatories (CO) are an essential tool to actively involve society to observe, understand, protect and enhance the environment (Liu et al., 2014). They are citizen science projects that involve multiple sectors of society to advance in scientific and social knowledge, not only to contribute to science and education but also to mitigate social inequalities and to solve local priorities and needs (National Academies of Sciences, Engineering, and Medicine 2018). They involve monitoring technologies, information gathering, data management and analysis, assessment and reporting systems (Liu et al., 2014).

CO face several challenges as effective local community participation, such as dealing with data privacy, accounting for ethical and security requirements, and considering data standards, quality and reliability. However, they have an enormous potential to influence good governance, if they develop community-based monitoring and information systems using innovative and novel Earth observation technologies, while promoting the sharing of technological solutions and community governance participatory methods among citizens (Liu et al., 2014). While knowledge transfer among diverse stakeholders is considered the key for CO (Liu et al., 2014), community-based science recognizes categories (stages) of participation defined as contribution, collaboration and co-creation (Grossberndt and Liu 2016), where the co-creation by different stakeholders with their diverse knowledge and experience into decision-making processes is essential (Conrad and Daoust 2008). Community member involvement in knowledge production has transformed attitudes and conferred good governance schemes related to nature, life quality and the implementation of good practices (Conrad and Daoust 2008).

As a transdisciplinary and participatory research endeavor, we emphasize two important distinctions from other COs. First, during all the DPOs’ development stages (design, planning, implementation and evaluation) we promoted the participation of multiple stakeholders to integrate their needs, interests, values, knowledge systems and decision-making practices and rules. Second, we use a complex system approach that investigates how relationships between a system’s parts give rise to its collective behavior and how the system interacts and forms relationships with its environment (Bar-Yam 2002). Overall SES dynamics are caused by connectedness, social-environmental contexts and the feedback of system components. The dynamic of a system is thus influenced by external drivers (i.e. climate change, policy change, fluctuations in markets) but also by how system elements (resources, species, social actors) disperse, migrate or interact across socio-ecological landscapes (Biggs et al., 2012). In order to understand SES dynamics and maintain favorable stable states, participatory transdisciplinary partnerships are needed that incorporate knowledge, needs and interests to co-produce diagnostics, monitoring and evaluation systems for the development of public policies.
As is the case for other COs, our DPOs are an example of a social innovation process and outcomes (Wehn and Evers, 2015) because it is a novel idea and practice for social value creation. Also, it aims to satisfy social needs and public services, while providing a more effective, efficient, sustainable and fair solution to socio-environmental problems (based on Phillis et al., 2008 definition of social innovation). Furthermore, social innovations can be defined as participative knowledge management to define projects, programs or public polices to improve individual and community well-being and quality of life by promoting freedom of choice (Martínez-Tagüeña et al., 2016).

Therefore, DPOs are a social innovation that provide services, activities, methods, alliances, among others, intended to improve welfare, well-being, and quality of life, especially among social groups who are underrepresented. Along these lines, they are a socio-ecological technology required to improve human well-being and the protection of the environment. DPOs envision the democratization of technology where all members of society have access and participate in collaborative projects that can be designed, implemented and self-managed by communities in novel ways. Thus, we have developed five DPOs to co-generate information for adaptive management of resources and services, alongside their sustainable use, to protect the biological and cultural diversity.

Materials and Methods

Study Sites

The DPOs were established in SESs with long-standing participatory research relationships among a multisectoral team. Two case studies were selected in a RISZA call for application. The case studies are: Observatorio Guadalupe (https://opsegualupeguadalupe.risza.mx), Observatorio Participativo Hant Comcaac (https://opsechantcomcaac.risza.mx), Observatorio Participativo Socio-ecológico Acuífero Cuauhtémoc y su Cuenca (https://opsecuahtemoc.risza.mx), Observatorio Participativo Socio-ecológico de la Biosfera de Mapimi (https://opsemapimimapimi.risza.mx) and Observatorio Participativo Socio-ecológico de la Región del Tokio (https://opsetokio.risza.mx).

While the numbers change constantly, so far, we collaborate with more than 13 local communities, 10 civil associations, five government institutions, 12 academic institutions and 8 businesses from the private sector. These observatories are long-term projects, whose longevity depends on local participation and their continued utility that emanates from the peoples’ needs and interests.

The initial stage I of ‘Diagnostic’ has been concluded; a detailed manual describes the systematic process of installation for future national and international DPOs (Huber-Sannwald et al., manuscript in file). This manual is essential and contributes to efforts to publish systematic, easy and reusable methods to establish COs (i.e. http://ceur-ws.org/Vol-1322/paper_1.pdf). As mentioned before, the selected case studies had previous data to reconstruct the historical trajectory of the SES and a map of actors and key stakeholders. They also had pre-established multisectoral teams and conducted a SWOT analysis on the current condition of the SES (Leigh 2009). Then, the installation of the DPO began with a participatory workshop to define goals and establish communication and integration mechanisms. In this workshop, various participatory tools were employed like ‘rivers of life’ to identify key historic facts relevant to the various participants and ‘cognitive maps’ to understand problems and how different society sectors make decisions. These methods allow the identification of differences and similarities between local populations, academics, technicians from civil society associations, and decision-makers, while they collectively co-produce knowledge.

The following phase was based on field work to identify research needs and project topics and their associated groups of actors. Methods like semi-structures interviews, focus groups and participatory mapping were used to conduct placed-based research with the various actors of the selected SES. In this phase, the various groups defined their ‘data sets’ stating what data they needed and how they wanted to monitor their productive activity, including the type of data, monitoring frequency, and privacy restrictions. A socio-ecological and multisector approach is employed to create complete and comparable data sets. At the same time, an expert team responsible for the Information Communication Technologies (ICT) developed an easy access user-friendly system to co-produce knowledge. It has a web portal, an application that can be used and accessed by mobile technologies, and field monitoring sensors that are integrated in a data management service with data storage support. As suggested in other COs, privacy issues are addressed though a combination of technology, legal regulations and social norms (Gianotti and Pedreschi 2010). Users choose the privacy level of their data set, anonymized accordingly to national and international data protection laws and standards, with ethical restrictions (based on Liu et al., 2015; 2017). Thus, a digital data repository was created ‘Repositorio Participativo...
del Desierto’ to host the information system of each DPO (https://repositorio.risza.mx).

Finally, Stage 1 concluded with monitoring using the mobile application that contains the various ‘data sets’ defined by the diverse groups in each case study. Also, a participatory activity with focus groups was implemented to better understand the decision-making processes at various scales, locally by each group corresponding to diverse themes like productive activities, and collectively as a DPO. We concluded with a virtual international event to present all the above mentioned, share experiences, develop an evaluation mechanism to assess effectiveness and efficiency, and plan the next Stage 2 for continuation.

Results
Stage 1 achieved the following goals: describe the SES; identify key actors and stakeholders; establish problems, needs and interests; co-produce socio-environmental histories; understand the decision-making processes of diverse sectors; identify priority zones in each territory; prioritize the ecosystem services for human wellbeing; co-design long-term monitoring systems; reconcile science and art to promote social innovation and technology adoption. We consolidated ‘placed-based learning communities’ formed by multisector actors. For example, ranchers and pastoralists expressed what data they needed and how they wanted to monitor their productive activity, emphasizing not only the type of data, but the frequency of monitoring and data evaluation and their privacy restrictions. They stressed the importance of collaborating with the younger members of their families to be able to understand and adopt the Information Communication Technologies (ICT). They were also interested in the various approaches used by researchers and technicians from civil associations and federal agencies to monitor “rangeland health”, which were reconciled and standardized for future comparisons. Alongside this effort, they also participated in the development of a Local Knowledge Index for Rangeland Health that includes knowledge on desirable plants, vegetation condition, regeneration potential, plant cover and soil stability (Mata 2019). Rural stakeholders, such as pastoralists, are key players and decision makers at the local scale, and their needs and knowledge are primordial for regional, national and international policy making. Through this project, we were able to identify the role played by each involved actor in the various steps of their decision-making processes, allowing the identification of gaps and opportunities for problem solving and more equitable power distribution (Huber-Sannwald et al., in process).

Conclusion
Pressing current dryland issues that are creating a voluntary or forced sedentarization of nomadic pastoralists are privatization of communal land, changes and access to markets, migration, expanding urbanization, investment in infrastructure for renewable energy generation (wind and solar farms) and intensive agriculture. Understanding specific historical, socio-cultural, socio-economic and socio-political contexts of diverse DPO will allow interregional, intercultural, inter-policy comparisons among similar dryland SES and their divergent responses to global environmental change drivers. Only then we will achieve the stewardship of future drylands and the sustainable development goals.

Acknowledgements
RISZA and its academic technical committee. All the collaborators in the DPOs. The following funding sources: Proyecto PDCPN_2017_5036, SEP-CB-2015-01-251388 and FORDECYT 296354.

References


Long-term socio-ecological research in the Biosphere Reserve in Mapimi, Mexico: a multidimensional participatory observatory of rangeland/pastoral systems

Reyes Gómez, V.M.; Huber-Sannwald, E.; Martínez Tagüeña, N.; Espejel Carvajal, I.; Lucatello, S.; Bowker, M.A.; Lauterio Martínez, C.L.

1Instituto de Ecología, A.C.; 2Instituto Potosino de Investigación Científica y Tecnología; 3Consortio de Investigación para las Zonas Áridas; 4Universidad Autónoma de Baja California; 5Instituto Mora, 6School of Forestry, Northern Arizona University

Key words: arid zones, conservation and protection of biodiversity; grassland and shrublands ecosystems, participatory research, transdisciplinary local incidence

Abstract
Since the creation of the UNESCO Biosphere Reserve Mapimi (BRM) in Mexico 45 years ago, pastoralism has undergone a series of transformations. Upon the arrival of the Spaniards, horse breeding flourished until 1900; thereafter extensive cattle production lasted for six decades. Only recently, farmers have adopted alternative management types for organic meat production. National and international efforts to achieve the Sustainable Development Goals (SDGs) require basic, applied, and participatory research efforts. In the socio-ecological pastoral system BRM, first halophytic ecosystems were examined for their ecohydrological role in rangeland productivity. In 1996, a long-term ecological research site was installed to monitor the effects of herbivores on the composition and biodiversity of desert communities. Shortly thereafter, the National Commission of Natural Protected Areas began a rigorous monitoring and conservation program to guarantee both the sustainable management of natural resources and the sustainable development of reserve dwellers. Soon international multisectoral institutions joined Mexican efforts to protect the natural, cultural, and social diversity of the BRM and to strengthen its socio-ecological resilience to climate change and land degradation. Hence, the BRM is currently a space of participatory monitoring and research, with emphasis on the health of this important socio-ecological pastoralist system. It is examined whether institutional programs promoting organic livestock farming are compatible with this desert system and how biological soil crust is developing as a fundamental indicator of soil functioning and the provision of ecosystem services and human wellbeing. The formation of multisectoral partnerships to foster dryland sustainability have led to the foundation of the International Network for Dryland Sustainability; it is currently coordinating a national network of participatory socio-ecological observatories (PSEOs) to promote the SDGs. Mapimi is one of the first PSEOs to promote local governance and social and ecological sustainable development in the drylands of Mexico and world-wide.

Introduction
In North America, the grassland biome extends from Alberta (Canada) (Figure 1), through a large part of central United States, to the vast central plateau of northern Mexico (Plateau) (CCA, 1999). Within these grassland areas, more than 55 protected areas have been decreed for the conservation of flora and fauna, including the “UNESCO man and biosphere reserves” with the mandate that resources use occurs in harmony with nature and in agreement with the locals and managers of the protected area; here we present the situation of the Mapimi biosphere reserve (RBM) (site 43 in Figure 1) (Halffter, 1988).

Materials and Methods
The dimensions and foci of research approaches in the Mapimi Biosphere Reserve socio-ecological system have evolved over time by increasingly strengthening integrated, interdisciplinary, inter-institutional conceptual frameworks and methodological strategies, coordinated by researchers in ecology, hydrology, vegetation, soil, and climate science and from the social sciences such as environmental and social anthropology, social geography, among others (Montaña, 1988; García Arevalo, 2002; Reyes et al., 2009). Originally, the main research interests were in basic conservation science; occasionally
combined with applied approaches. In general terms, the interaction with local decision-makers was low or null; they participated in field work as wage laborers. However, the MBR gave many undergraduate and graduate students from different backgrounds (Biology, Ecology, Anthropology, Agriculture, Geography) the opportunity to collaborate in a multidisciplinary fashion. In the third and fourth decade, after the creation of the biosphere reserve, public citizen consultation, action research, participatory inter-, and transdisciplinary research spearheaded long-term socio-ecological research targeting synergies among the interests of actors and sectors at the local, regional, national, and international level to support the SDGs and promote sustainable development in the participatory Observatory of the Mapimi Biosphere Reserve socio-ecological systems (Huber Sannwald et al., 2020).

Figure 1: Distribution of pastoral zones in North America, (adapted from CCA,1997)

Results and Discussion
Origin of the Mexican modality of biosphere reserves

In the 1970s, UNESCO promoted worldwide the creation of protected natural areas within the framework of the Man and the Biosphere (MAB) program; Mexico was the first Latin America country to create two biosphere reserves in desert and temperate regions. The Mapimi Biosphere Reserve was decreed MAB as the scrub and grassland biomes of this region represent the habitat of the desert turtle, an important endemic species in danger of extinction. Each MAB has to be affiliated with a group of local and regional scientists committed to conserve and sustainably manage the natural resources and operates based on by-laws that define both the physical-biological extension to be conserved and the management plan to be adopted for the protected area (Halffter, 1984). In 1977, the MBR went through its first stage, when a group of ecologists, the Durango state government and several local actors agreed to manage the MBR area, which had originally been declared Forest Protection Zone by presidential decree (CONANP, 2006).

On November 27, 2000, this area was officially declared the Mapimi Biosphere Reserve, covering land in the municipalities of Mapimi and Tlahualilo in the state of Durango; Jiménez in the state of Chihuahua, and Francisco I. Madero and Sierra Mojada in Coahuila, which together covered around 17,000 ha (Halffter, 1988).

From production and ecological research, combined with tourism, to conservation and management of the MBR socio-ecological system

Since the creation of the MBR, in 1977, the Institute of Ecology, A.C. (INECOL), promoted research in biophysical aspects, descriptive, taxonomic and functional ecology of fauna and flora, social geography, social anthropology, the monitoring of hydrological and edaphic processes, the use of natural resources including plant species of local interest (Mezquite, nopal, lechuguilla, cactus), potentially marketable species such as candelilla (wax), forage grasses, mining (salt and marble), among others. Research results advanced the understanding of the functioning of these diverse desert ecosystems, the reconstruction of the history of livestock production. Furthermore, clear shifts in the interest of knowledge generation were observed moving from disciplinary research to multidisciplinary, inter-institutional research agendas to protect, and conserve the natural resources with the support of local residents of
the ejidos La Flor, Carrillo, La Soledad, Las Lilas. This period generated around 320 scientific and popular articles, student thesis, chapters and books (CONANP, 2006), as well as various newspaper notes, videos, television programs, among others.

Parallel to the creation of the MBR, agribusinesses of the Comarca Lagunera, a nearby urban area, implemented an exploitative tourist strategy, to promote (uncontrolled) visits of the MBR, through the aggressive dissemination of alleged events (legends, paranormal phenomena and encounters with Martians), mystical zone theory, known under the collective phenomenon of the “Zone of Silence” (in many occasions it is more popular than the MBR itself), epitomized by myths of high magnetism in the area, the appearance of aliens, the fall of the Athena space capsule, megadroughts, the presence of plant species such as purple nopal (Opuntia violacea), caves, ferromagnesian minerals in the form of black concretions that visitors mistake for meteorites, capricious basaltic geoforms, and the presence of quartz and gypsum dunes, to mention the most important.

As of the year 2000, the Ministry of the Environment and Natural Resources (SEMARNAT), INECOL, various academic institutions, municipal governments and the political sector, defined by decree the National Commission for Protected Natural Areas (CONANP), responsible authority for the management of that socioecological MBR system. CONANP then developed the management plan of the MBR by citizen consultation which included the government, academia, producers, communal (ejidal) and private owners. This period CONANP underpinned the ordered and controlled management of natural resources to ensure sustainable development within the MBR by zoning the territory in a core zone, exploitation zone, buffer zone and zone of influence.

The MBR: a multifunctional participatory observatory in lands of pastoralism

The area of the MBR increased from 20,000 ha in 1978 to the current surface of 343,000 ha (since 2006). Land cover types within the polygon of the MBR have been reclassified. In the last two decades, an apparent shift in land cover and vegetation types has been detected by the National Institute of Statistics and Geography (INEGI) (Figure 2). Between 1993 and 2018 (see Series II and V of INEGI, in Figure 2 left and right, respectively) a shift occurred in that former secondary halophilic grassland vegetation was regrouped into secondary halophilic xerophilic shrub vegetation. The changes in land use and vegetation categorization identified between 25 years were mainly a reduction of halophilic grassland, and an increase in halophilic scrub; however this change is more related to a technical reclassification rather than to overgrazing or phenomena such as drought.

Figure 2: Cartography of land use and vegetation in the Mapimi Biosphere Reserve, Mexico used in the diagnosis of changes in surface area of grazing areas
Figure 3: Time infogram representing the evolution and shifts in research approaches in the Mapimi Biosphere Reserve, Mexico between 1975 and 2020

Figure 3 depicts a temporal infogram of the development from disciplinary to multi- and interdisciplinary participatory research approaches in the MBR (Halffter, 1984; Montaña, 1988; Grünberger et al., 2005). Participation has been among various national and international academic scientific institutions, decision makers, government representatives, local actors such as landowners, ejidatarios, and non-governmental organizations (CONANP, 2006; Grünberger et al., 2005). The most recent investigations have generated close partnerships among actors. With the support of multidisciplinary research methodologies, since 1997 the MBR has been considered a subject area for long-term monitoring within the network framework of the Long-Term Ecological Research (LTER) project, through a surveillance model inspired by complementary LTER sites in the La Jornada and Sevilleta in the United States of America (USA) (Jardel et al., 2014). Herbivore (native and domestic) exclosures were installed to examine their long-term effects on structural and functional changes of two representative vegetation communities of the Chihuahua desert, the microphilous desert scrub and halophilic grassland. The experimental design permitted to analyze the effect of both climate variability at long-term time scales (Reyes et al., 2009) herbivory by cattle, lagomorphs and rodents, the three most important groups of vertebrates of primary consumers in the food chain of these ecosystems. Through participatory action research, including a transdisciplinary multisectoral approach, the MBR installed a Participatory Observatory of Socio-ecological Systems (OPSE), through projects and research strategies developed by the International Network for the Sustainability of Arid Zones (RISZA). RISZA’s conceptual philosophy seeks to promote sustainable development and contribute to achieving the Sustainable Development Goals (SDGs) (Huber-Sannwald et al., 2020). Between 2017 and 2020, other participatory research groups have also considered the MBR, as demonstrative sites and transdisciplinary research to co-generate knowledge in a participatory manner aligned to local, regional, national, and international interests of dryland development, such as the CrustNET project: A global research network devoted to a unified understanding of the “living skin” of the Earth (Bowker and Huber, 2018) and The BIODESERT project: Assessing the impacts of grazing and climate change in global drylands (Maestre, 2016). These international projects focus on generating integrated knowledge on physical (climate, structure and hydraulic properties of the soil) and biological variables (biocrusts, grassland and scrub vegetation structure and function) under the long-term influence of livestock grazing. These projects were installed with the intent to understand the function of the socio-ecological systems of the MBR in areas of interests of local communities including private owners, ejidatarios, and civil associations interested in the conservation of species of forage interest, hunting and for the protection of the cultural and natural biodiversity of socio-ecological systems of arid zones.

Conclusions

The Mapimi biosphere reserve has undergone a long process of transformations in the way of conceiving it as a site for research, conservation and management of natural resources in arid zones. First, as a natural biodiversity protection zone, with the main endemic species of care, the pocket turtle Gopherus flavomarginatus; later, as a meeting place of knowledge between ecological scientists from Mexico and the world, to describe the biophysical environment and the functioning of the desert ecosystem. In the second decade after the creation of the RBM, a multisectoral consortium is developed for the management plan of the Reserve and the execution of seven local strategies to conserve, manage and advance towards sustainable development in agreement with local communities. During the last six years, transdisciplinary research groups have emerged...
that through participatory research create strategies such as the participatory observatory of the socio-ecological system of the MBR, in order to build new strategies that are aimed at subjugating the Sustainable Development Goals raised at the summit of Paris.

**Acknowledgements**

Many institutions, researchers, students, institutions and inhabitants of the MBR participated in the evolutionary process of research development in the MBR area; thank you too all of them. In particular, we would like to thank support by the Long-Term Ecological Research projects (INECOL-RED MEXLTER), the project to study saline soils in the Chihuahuan Desert Beaches (IRD-INECOL), the Integrated Study of Soil-Water-Vegetation Relationships in arid zones (INECOL-IRD), the project of the International Network for the Sustainability of Arid Zones (RISZA) “Participatory Observatory for the protection of cultural biodiversity and biotics of arid zones” (PN CONACYT 5036 including IPICYT, INECOL, Mora Institute, UABC, CIMAV, CIIIDZA) and by all people and institutions that are active members of the RISZA NETWORK. The preparation of land use maps was carried out by Hugo Fuentes Hernández from INECOL.

**References**


Comisión para la Cooperación Ambiental. 2010. Pastizales de América del Norte: Conservación de los pastizales de América del Norte mediante alianzas regionales, monitoreo de especies y programas de inventarios. CCA-CCE-CEC, Quebec, Canadá, www.cec.org/pastizales


Montaña, C. 1988. Estudio integrado de los recursos vegetación, suelo y agua en la reserva de la biosfera de Mapimi. Instituto de Ecología, A.C., Xalapa México. ISB]; 968-7213-09-4

A network of transdisciplinary observation mechanisms as a digital source of knowledge on rangeland, to communicate and exchange at local, regional and global scales

Rizzo, A.\(^1\); El Mahdad, E.\(^2\), Sifeddine, A.\(^3\), Lucatello, S.\(^4\), Bouchaou, L.\(^2\), Huber-Sannwald, E.\(^5\)

\(^1\)ESPACE-DEV, Univ. Montpellier, IRD, Univ. Antilles, Univ. Guyane, Univ. Réunion, Montpellier France;
\(^2\)Univ. Ibn Zohr, Agadir Morocco;
\(^3\)LOCEAN, Univ. Sorbonne, IRD, CNRS, MNHN, Paris France;
\(^4\)Instituto Mora, Mexico City Mexico;
\(^5\)IPICYT, San Luis Potosí Mexico.

Key words: citizen science; open data; sustainable development; observation.

Abstract
For several decades, interventions geared towards developing drylands have been the catalysts of much change in a rapidly evolving world. Learning how to build sustainable trajectories that consider both cultural and contextual variations is becoming of increasingly great import. As local problems become intertwined, and given the difficulty of large-scale collective action, understanding these dynamics requires cognizance of all levels of knowledge governance systems and their interactions. So far as rangelands are concerned, the lack of easily accessible documentation encompassing all knowledge to date is a major impediment to their sustainable development. With this in mind, polycentric governance would allow for centralized decision-making, giving rise to solutions that could be adapted to local conditions. Recent advances in technology and the proliferation of data are creating new opportunities for monitoring the progress and performance of multi-scale development efforts. Indeed, new and non-traditional data sources will be paramount to the success of such endeavours. For instance, participatory observation is an emerging example of a non-traditional data source that is already making a significant contribution and has fostered engagement at the community level. We seek to demonstrate the value of implementing transdisciplinary observation mechanisms—here, in relation to Southern Countries’ pastoral systems—and to provide concrete examples of how such mechanisms can be adopted for mainstreaming the use of data from a variety of sources, thereby facilitating the implementation of a sustainable development agenda as part of a continuous learning process. This project has been managed within the framework of the Agadir Platform, infrastructure supported and implemented by Ibn-Zohr University, Morocco.

Introduction
The last twenty years have witnessed significant advances in environmental governance, such as recognizing the importance of local resource management institutions, the introduction of laws on the regulation of environmental impacts, the development of community protected areas and common property systems, and increased management of collaborative efforts. In addition, attempts to broaden participation in environmental governance are found at the local and international levels, with the United Nations (UN) driving the impetus.

Since the 1972 United Nations Conference on the Human Environment in Stockholm, global environmental governance has become less State-focused. Civil Society has expanded its presence both in the implementation of environmental policy and in supporting the emergence of new institutions (Bernauer and Klöck, 2012.) It has become evident that engaging Civil Society would be necessary to foster a better-informed community and empower citizens to improve their health and well-being through informed decision-making achieved via a participatory observation process. This form of community-based environmental governance implies the participation of citizens in monitoring the quality of the environment they live in. Indeed, Environmental Governance considers the role of all actors that impact the environment. From governments to Non-Governmental Organizations (NGOs), the private sector and civil society, individuals and citizen groups, cooperation are critical to achieving the kind of effective governance that will lead the way towards a more sustainable future.
More recently, taking the example of the intergovernmental negotiations for the Sustainable Development Goals (SDGs), the interventions of Civil Society have encouraged a culture of participation in the creation of global policies on sustainable development. However, it had only a marginal effect on formulating the questions, the stance governments embraced, and the final agreement (A. Sénit 2019). Its involvement could, however, still play a role in the implementation of the SDGs by (i) defining national and subnational targets and metrics, (ii) monitoring progress and (iii) implementing the plan of action. Tracking the progress of these efforts requires a breadth and depth of data in areas where data coverage is often particularly weak today. A global sustainability framework would require public engagement to generate the societal transformations necessary to achieve the SDGs.

This is a challenging task for many countries around the world, with clear disparities in the wealth of available data and the ability of each country to provide consistent long-term data. While some indicators require local data, others could benefit from a more regional or global approach or a combination of the above. Furthermore, for some SDG indicators, data and processes are not yet defined (Tier III), which makes a one-size-fits-all approach impractical. How indicators are implemented depends on data availability, political and development priorities, capacity, existing data infrastructure, and institutional arrangements within each country. Today, there is an unimaginable range of indicators compiled by a wide variety of producers: civil society; academia; NGOs and the private sector (MacFeely and Nastav, 2019). Bearing this in mind, it is time to consider alternative approaches.

Most of the inputs to SDG reporting come from traditional sources of data collected nationally by public administrations. Although essential, this method has several limitations, namely (i) coverage: with data often being limited to areas with easy access; (ii) openness: as datasets are managed for internal use; (iii) timing: as data can quickly become outdated. New and non-traditional sources of data are therefore required. For example, data provided through participatory observation mechanisms could be used to complete and ultimately improve the SDG reporting process (S. Fritz et al., 2020). Below, we demonstrate the value of these data sources by creating a network of transdisciplinary observation mechanisms based on previous research initiatives carried out in the southern part of Morocco, the Souss-Massa region. We then inspect the concept of transdisciplinary observation through the prism of learning how to build sustainable trajectories that consider both cultural and contextual variations. Finally, we contend that the direct involvement of ordinary people—not just scientists and professionals—in the collection of data is key to harnessing the collective intelligence, distributed information, and knowledge and experience contained within individuals and communities, in turn filling the gaps that many regions still face. This analysis relies on initiatives developed in the North of Mexico in the framework of the international network RISZA and implemented within the Agadir Platform, of which the main objectives are to coordinate national participatory research networks as well as collaborative, transdisciplinary research efforts and training opportunities, and to build a cross-regional, coordinated research framework centered around the SDGs and focused on the sustainable development of local socio-ecological systems and the reinforcement of governance systems (A. Rizzo et al., 2020).

Materials and Methods

Study Site

The semi-arid climate of the Souss-Massa region located in southwestern Morocco is influenced by three factors: elevation, ocean coast, and the Sahara Desert. The north of the region, dominated by Atlas, is characterized by a semi-arid climate, progressing to a more humid climate as we descend towards the plain. The region’s centre, which occupies the southern valley of Atlas and the basins of Souss and Massa, is shaped by an arid climate despite a wide opening on the Atlantic. Finally, the southern and south-eastern part of the region, which makes up the northern side of the Sahara, is governed by the desert’s climate.

Precipitation varies highly with time and place, with an average rainfall of 200 mm/year (Bouragba et al., 2011; Seif-Ennasr et al., 2017). Recent studies on the role of decadal and multidecadal variability in the Atlantic Ocean have shown that the modes of multidecadal variability (AMO-Atlantic Multidecadal Oscillation and NAO-North Atlantic Oscillation) may lead to drought in Latin America (Brazil and Mexico) and Morocco but with very heterogeneous and antiphase expressions (Méndez and Magaña 2010). For example, a positive mode of AMO causes droughts in the Amazon region (Marengo et al., 2011), Northern Mexico, and

---

2 https://unstats.un.org/sdgs/iagc-iagc-sdg/tier-classification/ - Tier III: no internationally established methodology or standards are yet available for indicators, but methodology/standards are being (or will be) developed or tested.

3 RISZA – Red Internacional para la Sustentatbilidad de la Zonas Aridas
in mind and considering that tourism, agriculture and pastoralism are the major drivers of economic value in the region and that most rangelands in Morocco are found in arid and semi-arid regions, we have focused on this our activities in this area. Here, the absence of an easily accessible source of data aggregating all knowledge related to rangeland is a clear obstruction to the definition of sustainable development practices that consider both human and ecological dimensions (D-L. Coppock et al., 2017). This is all the more salient because Morocco is a developing country.

There remain severe doubts with regards to the openness and coverage of some of the official datasets, as nationally reported data cannot, by nature, be exhaustive in capturing variations across the country. However, defining coverage as the availability of data and openness as the level of access to this data, it is evident that the coverage gap must be filled if it is to be of any relevance. If national statistical capacities are not extensible, other ways should be explored to improve their local, regional, and national accuracy. One possibility resides in the empowerment of individuals and communities in monitoring activities through their participation in the establishment and development of permanent observation mechanisms, especially if we consider that 68% of the environmental SDG indicators lack data. Indeed, a participatory observation already contributes or could provide data to 40% of the environmental SDG indicators (D. Fraisl et al., 2020).

Taking the aforementioned into account, we conducted a study of some of the initiatives in participatory science carried out in the south of Morocco over the past few years. For the most part, these consisted of multidisciplinary operational research projects, mainly funded by local governance authorities or organizations responsible for natural resource management. These projects largely focused on developing and managing natural resources and were generally initiated by state services and communities, sometimes with the support of international cooperation organizations. We focused our analysis on use-cases studied by researchers in humanities and social sciences from the Ibn-Zohr University in collaboration with local actors in charge of natural resource management in the Souss-Massa region.

**Results**

The transdisciplinary observation was always a fundamental consideration in previous research efforts concerned with the orchestration of development projects. With the interactions between researchers and stakeholders in mind, transdisciplinary groups of observers were often set up during the preliminary stages of the strategic planning process. In addition, sessions aimed at conveying the research results to the Civil Society were carried out to reorient and supplement the diagnosis.

Owing to the different circumstances and challenges at play, there is still an obvious discrepancy between theory and practice on the question of data coverage. Generally, data reported nationally, such as the RGPH and the RGA, is structured based on municipalities, which are little more than national administrative breakdowns of the land. Any attempt to adjust them to accurately reflect spatial variation across the country would be a challenge, if not outright impossible. Thus, to complement this data at a more relevant and adequate scale, the participatory approach was used to glean information at the level of individual households and indigenous communities. Peculiar to Moroccan rural areas are the *douar* (village) for sedentary groups and the *frig* (group of tents) for mobile groups, nomads or transhumant communities. Due to accessibility issues and the limited time allocated to this type of research, observers often adopted the so-called RRA* approach, recommended by the FAO since the ‘80s.

Projects implemented during the last thirty years in the southern regions of Morocco—those with bioclimatic characteristics from semi-arid to hyperarid—were mainly concerned with local development dimensions related to the emergence of local governance systems for natural resources management and sustainability as well as the realization of infrastructures needed for improving living conditions (roads, sanitation, electricity). In principle, all Moroccan planning and development institutions have fairly detailed data repositories detailing their activities or areas of action, but they remain sectoral and difficult both to consolidate and to homogenise. In addition, these databases are generally not open sourced and their costs are too high for academic purposes.

**Discussion**

The Dubai Declaration, drafted after the 2018 UN World Data Forum, acknowledges “that the data demands for the 2030 Agenda require urgent new solutions that leverage the power of new data sources and technologies through partnerships between national statistical authorities and the

---

*RGPH: Recensement Général de la Population et de l’Habitat
RGA: Recensement Général de l’Agriculture
RRA: Rapid Rural Appraisal*
private sector, civil society, and the academia and other research institutions”. Implementing transdisciplinarity as a research model on sustainability can be a solution, but it poses various challenges: the inclusion of non-academic actors throughout the research process, the integration of different types of knowledge and worldviews, the development of appropriate quality criteria, and proper sensitivity to normativity. Observatories should enable participation and then contribute to environmental governance by providing relevant data and information that will help decision-makers make sound judgements globally, regionally and locally. Scientifically speaking, linking transdisciplinarity to participatory observation mechanisms is essential to go beyond disciplinary perspectives to establish holistic patterns taking systemic dynamics into account.

To develop a participatory observation tool, it seems necessary to improve the particular channels and mechanisms that underpin environmental-social-political actions in a way that facilitates society’s ability to influence environmental governing priorities and processes. Bearing this in mind, we argue for the need to build a long-lasting federated infrastructure that uses open and FAIR standards. The repository should be widely accessed, extended and maintained, and seen as a governance enabler rather than a project-specific outcome. This proposal envisions the creation of a regulated marketplace, where collectors try to enrich the governance indicators. Concerning the data produced by participatory observation, the following areas should receive careful consideration: (i) Data and metadata quality, especially when comparing crowdsourced and reference data, as defined by standard organizations; (ii) Data privacy and security, as sharing data requires strong ethical and security considerations, especially when it is produced by citizens; (iii) Data interpretation, with qualitative indicators developed in parallel with more quantitative indicators not solely based on individual perception.

The resulting network of transdisciplinary observation mechanisms rests on a peer-to-peer architecture based on open standard components. Linked data allows for publishing data in a standardized way and connecting it to other data sources, complementing it and thus providing a wider context. The ontology developed into the framework of a network of participatory observatories should be used to annotate the data gathered through these different sources, publish this annotated dataset as open data, and relate it to other linked datasets. It can provide a standard way to expose, share and connect data on global, regional and local scales. Generally, these data are not necessarily interoperable with systems officially employed. Further developments are necessary for data collection and analytical tools, data validation processes, and interoperability to ensure that the data are structured in a way that is of high quality, comparable, and could inform policy.

Acknowledgements
Special thanks to the CHARISMA project, supported by the Science and Technology Hassan II Academy, Morocco, for funding these activities. The authors greatly appreciate interactions and support provided by the international network RISZA (Network supported by CONACYT, Mexico) and the Agadir Platform (Ibn-Zohr University, Morocco).

References


Participatory management of rangeland hydrology – a new socio-ecological technology to effectively adapt to and mitigate climate change: case from Morocco

Bouchaou, L.; 1,2 Lhssaisoune, M., 3 El Hassan Beraaouz1, Sifeddine, A., 4,5 Rizzo, A.5,6 Hssaisoune, M1,7 Reddad, H8 Chehbouni, A.2,9 Huber-Sannwald, E.10

1 Applied Geology and Environmental Laboratory, Faculty of Sciences, Ibn Zohr University, Agadir, Morocco; 2 Mohamed VI Polytechnic University, International Water Research Institute (IWRI)/, Benguérir, Morocco; 3 Department of Geography, Faculty of Languages and Human Sciences, Ibn Zohr University, Agadir, Morocco; 4 IRD, UMR LOCEAN (IRD, CNRS, Univ. Sorbonne Université, MNHN), France, Mexico; 5 ERC2-Université Quisqueya; 6 IRD-ESPACE-DEV, Montpellier, France; 7 Faculty of applied Sciences, Ibn Zohr University, Ait Melloul, Morocco; 8 Sultan My Slimane University, Béni Mellal; 9 IRD, CESBIO, Toulouse, France; 10 IPICYT, San Luis Potosi-Mexico

Key words: Rangeland; arid zones; climate change; water management; pastoralism

Abstract
Morocco’s drylands cover over 90% of the land area; low and irregular rainfall and high potential evaporation contribute to extremely high-water deficits. These phenomena have greatly impacted rangeland hydrology and nomadic and transhumant pastoralism. To adapt to this predominant water deficit, the inhabitants of these areas have developed two forms of lifestyles, which include household and livestock mobility: (i) a pendulum movement for seasonal transhumance between the mountains and their bordering plains; and (ii) random nomadic mobility regulated by the sporadic frequency of rains and thus water availability. In both cases, this mobility is controlled by the degree of development of the routes, but it derives also from participatory governance of water access to livestock. For example, pastoral communities first use routes with ephemeral waters, while saving perennial or semi-perennial water sources for long lasting drought periods. To mitigate water scarcity, nomads and transhumants often reduce herd size, and switch temporarily to complementary activities such as trade, crafts, wage labor, and engagement in public services. The conservative practices of rangeland and water management have progressively declined following regional and global trends of sedentarism, urban extension, and the emergence of new activities such as intensive irrigation, industry, and tourism. Faced with this situation, various development organizations aim for the recovery of local traditional conservation and participatory water management practices. Rainwater harvesting as well as hydraulic facilities, storage and tank services for isolated populations are being implemented at several points along nomadic routes. Besides, new schooling opportunities have opened employment options and additional income from farming activities. In this context, transdisciplinary monitoring of rangeland development through remote sensing in addition to biophysical and socio-economic indicators have been installed. In this work, we present an integrated analysis of hydrological management systems of Moroccan drylands in relation to pastoral adaptation to climate change.
Introduction

Morocco is one of the semi-arid countries with a significant pastoral vocation. The agrosylvo-pastoral, pastoral and oasis lands cover more than 90% of Moroccan territory (Ministry of Agriculture, 2015). These lands offer an important land support dedicated to extensive livestock farming which play a major role in the income generation for peasant society and in the functioning of the rural economy. Its production is about 1/3 of added-value in agricultural sector, contributing to 30% of jobs in the sector. More importantly, it represents a source of income for 80% of rural households (Qarro et al, 2010).

Most of the rangelands (97%) (oasis 7 %) are located in arid and semi-arid environments where the chances of success of rain-fed cereal crops are closely related to the frequency of droughts (Araba and Boughalmi 2016; Reed and Dougill 2002). The North Africa drylands will face increasing temperatures with climate change and experience disruptions to their hydrological cycles with a pronounced tendency of reduction of precipitation exacerbating water scarcity and social conflicts over water allocation (Hssaisoune et al., 2020; Thomas, 2008).

Over centuries and decades, pastoralism in arid areas has been considered a crucial economic activity and a method of land use. Under these conditions, the possession of small flock becomes a strategic way of ensuring the subsistence of human communities especially in the context of climate variability. In addition to the characterization of the socio-ecological frameworks for the land use of Moroccan pastoral territories, the main objective is to re-examine the traditional pastoral activities and management of water resources in the light of technological innovation to better mitigate and adapt to climate change and variability.

Materials and Methods

Study Site

The methodology used in this work focused on transdisciplinary, multidisciplinary, collective action. We applied literature reviews, field observations, and included experiences from researchers from different disciplines. A special focus was made on research that was carried out with the objective to tackle sustainable development by safeguarding and conserving the fragile pastoralist ecosystems. In this study, we are referring to: i) studies on the exploration and development of water supply systems for rural populations and their livestock, ii) establishment of National Parks and Biosphere Reserves for the conservation and rehabilitation of declining ecosystems, and iii) delimitation and characterization of pastoral and agro-sylvo-pastoral zones. We performed a reviewing of accessible documents such as reports of inedited studies and publication of different research results that constitute an added value to this paper (Ahlafi 1999; FAO 2006; Neggar 2018; Qaro et al., 2010). The choice of Moroccan drylands was justified for several reasons: i) decreasing trends of production capacities in arid and semi-arid ecosystems; ii) the degradation of old legacy systems of governance of scarcity resources under effect of extensive migration caused by youngsters, producing a break in the line of expertise transmission between different generations; iii) different actors and partners’ interests in aiming at reconciliation between development and the safeguarding the equilibrium of arid and semi-arid ecosystems; iv) the socio-economic importance of pastoralist environments which constitute the veritable in-situ laboratories for participatory observation and analysis of the socio-ecological systems in the light of extensive use of rangelands, as well as the monitoring of the mitigation aspects and especially the adaptation of climate change effects.

Results and discussion
Pastoral area and socio-ecological framework of exploitation

The pastoral lands cover more than 87% of national territory which corresponds to more than 71 million Ha. Forest and scrubland (matorral) areas constitute only 10%; while land classified as rangeland and uncultivated land covers more than 55 million Ha, this is 90% of the pastoral area. These grazing lands, without the forest rangeland, consist mainly of steppes at the rate of 94%, the rest concerns land covered with alfà formations (Stipa tenacissima).

Ecologically, most of the potential of rangelands extends in the areas with extreme edaphoclimatic conditions, with water shortage due to a high frequency of seasonal and interannual drought periods (Qarro et al., 2010):

Saharan rangelands: mainly cover the provinces of southern Morocco with an area of around 50 million ha, more than 4/5 of national rangelands. The hyperaridity of the environment contributes to the reduction of the rates of floristic richness and recovery of vegetation, and to the regression of water resources. The possibilities of using the rangelands can only be sporadic during irregular rainfall events;
Pre-Saharan rangelands: located further north where the more favorable bioclimatic conditions allow the development of steppe plant formations dominated by Saharan strains. This area is a modest extension of 10% of all rangelands, but it remains strategic for the maintenance of pastoral activity through its forage supply of perennial xerophyte shrubs and its potential for livestock watering;

Eastern rangelands: these are steppe lands representing 8% of the total rangelands. These lands are dominated by a plant formation of alfa representing a species adapted to arid or semi-arid bioclimatic conditions.

Socio-ecological systems of rangelands and water governance

Human presence in drylands has only become possible through the shaping of ingenious socio-ecological systems based on adaptive mobilization and management of natural resources. In the case of nomads and transhumants, livestock’s watering needs control the movements of the herds and households between water points. Historically, pastoral activity has been practiced without any significant hydraulic development. The most widely used surface waters are those of isolated ponds (Dayat, Graara) and receding ponds of wadis (Gueltas), while groundwater is limited to resurgences of underflows of wadis (Aayn). More often than not, to quench their thirst, livestock use the same water resources as is used by wild animals.

When the mobilization of greater volumes of water becomes unavoidable to increase the duration of grazing of pastures, the communities pass by collective hydraulic installations mainly of using and storage. The most adopted technique is the digging of wells (Bir, Hassi) for the extraction of water from the shallow aquifers generally attached to infra-flows of permeable alluvium. In pre-Saharan areas where the potential of underground resources becomes relatively important, pastoral communities may have the possibility of benefiting from groundwater springs (Ayn) and underground drains with accumulation basin (Khettaras and Charij). On the other hand, for surface water, the most frequent developments consist in collecting rainwater and runoff: reservoirs covered with impluvium (Notfias) and open excavations (Ghidir). The mobilization and use of water resources are subject to a rigorous and collective management system with the rights and obligations of individuals. Under climate change conditions, the groundwater extraction is the more reliable water resource. Moreover, during the last decades the government, through its different services, encourage the rain water harvesting especially by small dams (hill dams), in order to ensure drinking water for both local population and livestock. This last technique can play dual role, the first is surface water storage and the second is groundwater recharge.

Rehabilitation attempts and experiences of stakeholder participation

The pastoral areas in Morocco are more than ever subject to pronounced stresses due to overexploitation of rangelands combined with shortage of water (Del Barrio et al., 2016; Kouba et al., 2018). Hence, attempts to rehabilitate the pastoral socio-ecological framework are underway in these areas. They include various decisions, such as national rangeland development strategies; emergency drought response programs; the rangeland and livestock development projects; biodiversity conservation projects through transhumance in the High Atlas, projects to install national parks and biosphere reserves. Currently the ministry in charge has just launched a study of demarcation, inventory and characterization of the rangelands with the objective of creating pastoral and sylvo-pastoral spaces in the twelve regions of the country. The development and implementation processes of the various programs and projects have provided precious opportunities for adopting horizontal approaches favoring the principles of consultation and citizen participation as well as all stakeholders. These new approaches, which put those concerned at the center of the development process, have been successful in improving the living environment of pastoralists, and in supporting their activity by installing more efficient hydraulic equipment, but without being able to curb the trend of disappearance of nomadic and transhumant lifestyles.

Conclusion

Even though the water supply systems used for livestock may appear to have poor to moderate yields. The traditional pastoralist socio-ecological systems are recognized by their high capacity to adapt to the fragility and irregularities of local water potential. For the community of scientists engaged in the processes of finding the best practices facing mitigation and adaptation to the effects of climate change, the traditional pastoral systems developed in the past by nomadic and transhumant societies in arid and semi-arid environments turn out to have a vital interest. However, these traditional pastoral systems seem to be in a phase of regression marked by increasing loss of local expertise and traditional knowledge, which has been caused by an increasingly intense sedentarization. Complex factors have contributed...
to the trend of spatial fixation and intensification of this former mobile pastoral activity. Besides of important ecological characteristics, the factors of change in these pastoral systems have economic, social and political dimensions. We cite in this context, the closing of international borders for various pretexts, increasing urbanization and the desire of pastoralists to improve the standard of living, growth of population and food needs and the shift towards intensification of breeding.

In synthesis, currently all development action of arid and semi-arid pastoral areas, carried out by the State and pastoral partnerships, is mainly oriented towards pastoral hydraulics with the objective of improving the water supply. Such actions only facilitate the fixation of nomadic and transhumant societies, which ends in the exhaustion of the regeneration capacities of pastures, the loss of a highly functioning adaptive pastoralist system and consequently jeopardizing food security.

Acknowledgements
Special thanks to the CHARISMA project with the assistance of the Science and Technology Hassan II Academy-Morocco. The authors greatly appreciate interactions and support provided by the international network RISZA (Network supported by CONACYt-Mexico) and the Agadir Platform (Ibn-Zohr University).

References


Key Note Papers
Exploring the information base needed for sustainable management of rangeland resources for improved livelihoods

Johnsen, K.I.¹; Niamir-Fuller, M.⁴; Bensada, A³; Waters-Bayer, A.²

¹Norwegian Institute for Water Research (NIVA); ²Independent consultant; ³UN Environment; ⁴Agrecol Association / Coalition of European Lobbies for Eastern African Pastoralism (CELEP)

Key words: Pastoralism; rangelands; definition; disaggregation; devaluation

Abstract

Pastoralism is one of the most sustainable production systems worldwide and plays a major role in safeguarding ecosystem services and biodiversity in rangelands. The unique biological and cultural diversity of rangelands contributes to goods, services and knowledge that benefit humans also beyond the herding communities.

Yet data currently available on grassland, forestry, agriculture and livestock are inadequate for informing policymaking on rangeland-based livestock systems. A review of global environmental assessments, online databases, peer-reviewed literature and international project documents showed that available information seldom disaggregates rangelands from other ecosystems or pastoralists from other rural dwellers. Few peer-reviewed publications address pastoral and rangeland issues combined. While some international projects present contextualised information on cases of pastoralism and rangelands, most do not share the data on their websites.

A challenge encountered when seeking information is the inconsistency in defining pastoralists and rangelands. Estimates of the total number of pastoralists vary from 22 million to over half a billion; estimates of area covered by rangelands vary from 18% to 80% of the world’s land surface. The variation in definitions and lack of disaggregation of data lead to significant knowledge gaps on the condition and trends of pastoralism and rangelands.

These therefore tend to be devalued. Underrating benefits of livestock mobility and inaccurate data on rangeland degradation could cause governments to blame and dismantle traditionally sustainable pastoral systems – in other words, ‘fix’ something that’s not broken. Without good data on pastoralists and rangelands, the impacts of current policies on these livelihoods and ecosystems cannot be assessed, and sustainable use and management of rangelands for improved livelihoods may be hindered.

Improving the information base is high on the agenda of the initiative for an International Year of Rangelands and Pastoralists to increase global awareness of the importance of rangelands and pastoralists for livelihoods and healthy ecosystems.

Introduction

This paper is based on a study conducted on behalf of the United Nations (UN) Environment Programme in 2017–2018. The study is a response to a UN Environment Assembly resolution, which called for a gap analysis of environmental and socioeconomic information and the provision of technical support for promoting pastoralism and rangelands.

Very broadly, one could say that rangelands are areas that are grazed or have the potential to be grazed by wild animals and domesticated livestock. And that pastoralists are people who raise or care for wild or semi-domesticated animals or domesticated livestock on rangelands. Pastoralism is practised by millions of people worldwide and represents an intimate relationship between people, the animals they care for and the landscape. This livelihood is increasingly
recognised as one of the most sustainable production systems on the planet and plays a major role in safeguarding ecosystem services and biodiversity in rangelands. The unique biological and cultural diversity of rangelands contributes to goods, services and knowledge that benefit humans beyond the herding communities. Such benefits include food security, medicine, local and regional economies, wildlife, tourism, carbon sequestration, and land and water preservation and rehabilitation.

It is often assumed that data currently being collected on grassland, forestry, agriculture and livestock are adequate for informing policymaking on rangeland-based livestock systems. However, our study of available information on pastoralism and rangelands revealed that there are significant gaps – and that these gaps are not even realised by policymakers, who do not recognise and value these people and landscapes (Johnsen et al., 2019).

Without greater awareness and deeper knowledge, policymakers cannot judge the impacts of their policies on pastoralists’ livelihoods and ecosystems. We regard this situation as a “case of benign neglect” – therefore the title of our study report.

**Materials and methods**

In essence, the gap analysis investigated whether relevant and sufficient information about pastoralists and rangelands is available for policymakers to be able to create enabling conditions for sustainable use and management of rangelands for improved livelihoods.

The thematic scope of the study was inspired by the conceptual framework for assessments developed by the Inter-governmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES). It covered the nature of rangelands; the benefit of rangelands to people; pastoralists’ wellbeing; pastoral assets; and direct and indirect drivers of change over time.

The methodology was further developed through a dialogue with a multi-stakeholder working group, which helped us identify relevant sub-themes and develop sets of keywords for identifying the data we sought (Chen and Liu 2010). Keyword searches were then made in sources for environmental and socio-economic information that were available online in English. The gap analysis consisted in a rapid study over 15 months, covering relevant information available since the year 2000. Because of time and resource constraints, we could not cover non-English information.

With the sets of keywords in place, we sought words related to pastoralism and rangelands in 100 global, regional and national databases and websites, and within Scopus – an online database of 71 million peer-reviewed research publications. We also reviewed 13 global environmental assessments and online sources of 13 multilateral agencies and international research organisations. To assess the quantity and quality of information available, we analysed the accessibility and availability of and level of confidence in the data on pastoralism and rangelands in the sources reviewed.

To further inform the gap analysis, we sent a questionnaire to 336 stakeholders (pastoralists, researchers, NGOs) in different regions. The response rate of the questionnaire was only 18%, but the survey gave some nuances which the document analysis did not provide and confirmed trends we observed in the material reviewed. A final worldwide peer review verified the conclusions and recommendations of the study. Therefore, despite some limiting factors in the gap analysis, we are reasonably confident in the relevance of our findings.

**Results**

We found that, while global environmental assessments were generally easy to access and the confidence level in the data presented was generally high, none of the 13 assessments reviewed disaggregated their information on pastoralists or rangelands.

Only one third of the databases and websites reviewed included the keywords ‘rangeland’, ‘pastoralism’ or ‘pastoralist’. And out of these, only two databases were both highly accessible and provided detailed and contextualised information in a manner that could help inform decision-makers about rangeland management or sustainable pastoral livelihoods.

Within Scopus, less than 3000 publications included keywords related to both ‘rangelands’ and ‘pastoralism’; however, the trend shows that the publishing of this type of literature has increased markedly since the year 2000. Within the 3000 publications, we found that keywords that are typically related to natural sciences have more hits than keywords typically related to the social sciences. And in general, the Scopus literature appears to have more focus on basic descriptors for pastoralism and rangelands, rather than on the root causes affecting the wellbeing of pastoralism and rangelands. The stakeholder survey supported this observation.
Reviewing the provision of technical support for pastoralists was challenging because the data were not disaggregated. For example, we could not tell what proportion of official development assistance related to livestock reaches pastoralists and rangelands. While we know that international development projects typically collect field data, such as human population numbers, livestock numbers, or geography and land-use patterns in their target zones, such data were usually not readily available on their websites. Only around half of the multilateral organisations assessed provided an open database where projects can be reviewed. We looked further into the website of the Global Environment Fund (GEF), as it provided open access to its project portfolio. We searched for keywords in the project descriptions and found that projects that contain terms related to pastoralism and rangelands comprise only 1.2% of available funding. Among these projects, there was a key focus on capacity-building, biodiversity conservation and institutional development.

The choice of keywords and their metonyms was of particular importance in the gap analysis, because of the immense variation in definitions and usages across regions of the world. This word cloud presents the relational difference between metonyms according to how often they appear in Google. The more often the words appear, the bigger they appear in the word cloud. Cartography by Levi Westerveld/GRID-Arendal.

**Discussion and Conclusions**

The study revealed several gaps that may affect policymaking on rangeland-based livestock systems. These can be summed up in three words: definition, disaggregation and devaluation.

**Firstly:** A challenge for the study is the inconsistency in how pastoralists and rangelands are defined. Estimates of the total population of pastoralists varied from 22 million to more than half a billion people. And the estimates of area covered by rangelands varied from 18% to 80% of the world’s surface. Within the English language, there are cultural differences in how terms referring to rangelands are understood and used: prairie, steppe, bush, etc. And while the nuances in terms used for pastoralists – shepherd, Bedouin, nomad, etc. – reflect a diversity of cultures and practices, it also complicates the task of identifying existing knowledge and current gaps regarding pastoralist communities across regions of the world.

**Secondly:** While the UN has compiled and assessed data and trends on various regional and global environment and socio-economic issues, the assessments tend not to disaggregate natural rangelands from other habitats, and pastoralists from other rural dwellers. Common terms used in discussions about pastoralism and rangelands – for example, ‘pastures’ and ‘livestock’ – do not differentiate between extensive and intensive animal production. In databases, it is rare to find ‘pastoralist’ as a category. Pastoralists are often simply included in the category ‘farmer’ or ‘livestock-keepers’. And statistics on ‘livestock’ tend not to differentiate between livestock of pastoralists and livestock in large-scale commercial feedlots.

**Thirdly:** The variation in definitions and the lack of disaggregation of data lead to a significant knowledge gap on the condition and trends of pastoralism and rangelands. Thus, although pastoralist societies have existed for millennia, little is known about them or about the interlinkages between their practices and the rangelands on which these depend. A consequence is that pastoralism and rangelands tend to be under-recognised and undervalued. Due to their extensive use of rangelands, pastoralists – especially nomadic and remote pastoralists – have different interests and needs than most other people. Rangeland ecosystem functions and services are very different from those of forests or croplands. Underestimating the number of pastoralists and underrating the benefits of livestock mobility may mean that policymakers do not realise the different needs, circumstances and opportunities for sustainable pastoralism and rangeland management. Inaccurate data on rangeland degradation could cause governments to blame and dismantle traditionally sustainable pastoral systems or, in other words, ‘fix’ something that is not broken.

On account of the huge information gap, there are currently many questions that cannot be answered with confidence; for example: Who are pastoralists and how have their lives changed in the past few decades? Where are their natural rangelands located? How does land-use policy affect their land and livelihoods? How does climate change...
affect them? How can policymakers best support and promote sustainable rangeland management and pastoral livelihoods?

To start addressing these questions, and to make available appropriate data for policymaking and planning, we suggest the following to the international community:

1. Provide sufficient funding and resources to address information gaps on pastoralism and rangelands through an intergovernmental, multi-year, integrated global assessment, which is participatory and addresses also terminology so as to gain a common understanding on pastoralism and rangelands.

2. Develop national and international information systems to enhance the availability and quality of existing information on pastoralism and rangelands, and include pastoralists’ knowledge to understand the specifics of and dynamics between pastoralism and rangelands. This includes using appropriate indicators for measuring the wellbeing of these coupled human-nature systems. For example, indicators from intensive livestock production, where the main objective is to optimise the output of meat, milk or wool, are not suited to assess extensive pastoralism, where production is just one of many objectives. Pastoralists seek to maximise the quality of forage available for their livestock by moving their herds (Krätli and Schareika 2010). Therefore, indicators used to assess sustainable pastoralism must reflect a production system that produces food and other values in areas not suited for crop production and in landscapes with asymmetrical distribution of and seasonal changes in forage availability.

3. Increase funding and resources for participatory research on pastoralism and rangelands, and ensure that ‘non-typical’ topics are addressed, such as those related to herd mobility, vocational and practical education, investments, pastoralist women and youth, and the need for covering both developing and developed countries.

4. Develop a suitable methodology and assess the extent to which technical support provided to pastoralists is based on identified needs and interests.

5. Engage pastoralists and pastoralist civil society organisations in global assessments to ensure the appropriate inclusion of local and indigenous knowledge and technology, as well as effective representation of different pastoralist constituencies. This will broaden the global understanding of the natural and cultural value of pastoralism and rangelands, and the effects of environmental change on pastoralist livelihoods to enhance sustainability and resilience.

An attempt to put these issues higher on the international agenda – and to increase the global awareness of the importance of rangelands and pastoralists for livelihoods and healthy ecosystems – is the global initiative for an International Year of Rangelands and Pastoralists.

Acknowledgements

The study draws on input, advice and support from ongoing discussions within a large community of academics, pastoralists, government officials and other experts.

References


Sustainable use of grassland resources for improved livelihoods

Liana Jank¹, Cacilda Borges do Valle¹, Rosangela Maria Simeão¹, Roberto Giolo de Almeida¹, Mateus Figueiredo Santos¹, Sanzio Carvalho Barrios¹

¹Embrapa Beef Cattle, Rua Radio Maia, 830, Campo Grande, MS, Brazil

Key words: breeding, genetic resources, forages, impacts

Introduction

Grasslands occupy about 80% of global agricultural land and represent a wide range of ecosystems (Bosi et al., 2020). Pastureland represents approximately 889 million ha in Africa, followed by China (~506 million ha), Oceania (~345 million ha), Asia (~307 million ha, excluding China and India), United States (~252 million ha) and Brazil (~149 million ha) (Goldewijk et al. 2017; Bosi et al. 2020; Landau et al., 2020). Rangelands alone are the world largest land surface, and in 28 countries they represent more than 60 percent of total land area (FAO, 2009). The livelihoods of almost one billion people depend on grassland, thus improved management of grasslands is key to food production and sustainable development in many countries (FAO 2009).

In general, animal production based on pastures is less geographically constrained than crop production and may occur in more diverse types of environmental conditions (Roser and Ritchie 2019). However, in the face of world human population growing expectancies in the next few decades, the pressure for more animal products, such as milk and beef, will increase. Production will have to increase 57% for beef and 48% for milk by 2050 compared to that in 2005, as projected by FAO (Alexandratos and Bruinsma 2012), while other estimates indicate that the global demand for livestock products will double by 2050 (Bajiţelj et al., 2014; Rao et al., 2015). This higher production needs to consider scenarios where land for pastures may have to be reduced in response to a number of reasons, as has been happening in Brazil (Martha Jr. et al., 2012; Landau et al., 2020), which, in turn will demand greater productivity per area.

In recent years, global agricultural activities have been required to adopt environmentally friendly production strategies to reduce the opening of new unexplored areas and thus reduce the impact of climate change (Schultze-Kraft et al., 2018). Therefore, the challenge faced by both agriculture and animal production nowadays is to produce more in order to meet the increase in domestic demand and exports, but without expanding the cultivated area already in use complying with sustainability.

The strategies to accomplish sustainable pastures globally tend to be vast and heterogeneous. The most frequent and important challenge cited in the literature is the prevention of loss of perennial grass productivity through the years; followed by soil degradation and decrease in animal weight gains. Looking ahead, these stresses are projected to intensify due to heat waves, frequent droughts and less water availability and their competition for crop and human use. It is predicted that all climate changes will affect ecosystems and economics through diminished rangeland carrying capacities, increased site vulnerability to soil degradation, compromised regional feed and pasture forage production, and intensified animal heat stress (Havstad et al., 2018; Spiegal et al., 2020). In addition, new biotic stresses caused by insects and diseases have also been observed as never before in cultivated pastures.

The environmental impact of the animal industry has received increased public attention due to its perceived effects on climate change (Thompson and Rowntree 2020). However, it is impossible to socially address hunger eradication and ensure human food security without addressing animal production and
its importance in the survival and livelihood of more than half of the world’s population (FAO 2018a). Livestock production allows food production on 57% of the earth’s land that cannot be used for crop production (Mottet et al., 2017); and livestock production supplied 25% of protein and 18% of calories consumed globally in 2016, both of which are required for nutritional security (Mottet et al., 2017).

This paper presents and discusses some strategies being adopted to improve sustainability of grasslands, with emphasis on tropical regions and cultivated pastures.

**Main body text**

**Sustainability strategies**

Nowadays, and more than ever, after the release of the latest 2021 IPCC Report, sustainability must be sought. Sustainability involves the needs of the present generation without compromising the ability of future generations to meet their own needs to fulfill their aspirations for a better life (Report of the World... 1987). In agriculture, sustainability is directed to satisfying human food and fiber needs; enhancing environmental quality and natural resources; making the most efficient use of nonrenewable resources and on-farm resources and integrating, where appropriate, natural biological cycles and controls; sustaining the economic viability of farm operations; and enhancing the quality of life for farmers and society as a whole (USDA 2007).

Pasture sustainability is a must, and many possibilities and strategies are available. In general, well managed high quality improved forages are more efficient than native pastures, by their increased production and quality, despite the existence of very productive nutritious native pastures. The higher production may contribute to release land for other uses and the higher quality and better pasture management may contribute to reduce methane emission from animals (Souza Filho et al., 2019). Thus, breeding to improve forage quality and production is a large contribution, not only for the animal production chains, but also to the environment and to alleviate climate change. An even better proposal is the use of integration with crops which may increase crop production (Szymczak et al., 2020), improve soil quality with consequent increase in animal performance. The use of integration with trees, may increase C sequestration and thus neutralize GHG emission from animals (Alves et al., 2017).

The main available strategies for increased sustainability are intensification due to the adequate use and management of the pastures and animals, correct use of soil conservation practices and recovery, integrated systems with crops and integrated systems with trees and a forest component. The practice of using trees is very common in Asia in small-scale farms, which, at the same time as animals are reared, trees are exploited, as coconut tree, as an example (Salendu et al., 2018; Deepthi et al., 2021).

According to Rao et al. (2015), sustainable intensification improves the productivity of tropical forage-based systems, decreases the ecological footprint of livestock production and generates ecosystem services, as improved soil quality and erosion reduction. These authors developed “The LivestockPlus concept” (Figure 1) that shows how properly managed improved forages may result in sustainable intensification of mixed crop-forage-livestock systems in the tropics, respecting social, economic and environmental objectives. For this, there must be a synergism between soils, plants, animals, people and the environment. Four principles are involved in producing more meat and milk. These are the use of sown pastures; sown pastures in combination with crop residues; sown pastures integrated with crops and trees; and actions that are essential for the adoption and widespread use of improved forage-based systems, including genetic improvement of livestock, changes to regional and national policies and increases in human and social capital. Thus, the benefits for improved livelihoods include more milk, meat, eggs, manure use, adaptation to climate change, food security, income generation, poverty alleviation and improved family nutrition (Figure 1).
LivestockPlus - the sustainable intensification of forage-based systems

Three intensification processes
- Genetic
  Improved forage yield, quality, stress resistance
- Ecological
  Better management of forage-based crop-livestock-tree systems
- Socio-Economic
  Creation of enabling environments (markets, policies, social & human capital)

LivestockPlus: A concept to improve livelihoods and ecosystem services via the sustainable intensification of forage-based crop-livestock-tree systems (Rao et al., 2015).

Livestock manure provides organic fertilizer for over 50% of the world’s croplands, converting waste products into inputs for production of high-value food (Bruinsma 2003; FAO 2018b). The manure plays an important role in replenishing soil organic matter, which is critical for maintaining soil health and quality and hence sustaining crop productivity and restoring degraded soils (FAO 2018b). Animal based food production contributes meaningfully to goals for a sustainable food system, by converting millions of tons of agroindustrial by-products that cannot be consumed by humans into livestock feeds, concomitantly reducing waste and environmental pollution and increasing human-consumable food. It is critical to note also that globally, only about 14% of the feed dry matter ingested by livestock is edible to humans, based on recent FAO data (Figure 2, Mottet et al., 2017), and probably even lower in several developing countries where ruminant livestock subsist mainly on pastures or crop residues.

Figure 1. LivestockPlus: A concept to improve livelihoods and ecosystem services via the sustainable intensification of forage-based crop-livestock-tree systems (Rao et al., 2015).

Figure 2. Global livestock feed dry matter intake. (FAO 2017; adapted from Mottet et al., 2017).
Examples from Brazil

Brazil with its 118 Mha of cultivated pastures is the country with the largest extent of planted tropical pastures in the world. For this reason, many of the examples used in this paper will be from Brazil. Many initiatives have also been previously discussed and reported by Euclides et al. (2010) and Almeida et al. (2013).

Several programs have been and are being developed and implemented in Brazil to meet the goals of decreasing greenhouse gas emissions by 37% by 2025 and 43% by 2030 (Government of Brazil 2021). The ABC plan was created by the Brazilian Government in 2010 and is one of the main political policies for a Low Carbon Emission Agriculture and is strongly based on technology transfer involving soil conservation, direct planting system, and crop-livestock-forest integration to mitigate GHG emissions from agriculture. It was structured into seven Programs: 1) Recovery of Degraded Pastures; 2) Integration of Crop-Livestock-Forestry (ICLF) and Agroforestry Systems; 3) Direct Planting System; 4) Biological Nitrogen Fixation; 5) Planted Forests; 6) Animal Waste Treatment; and 7) Adaptation to Climate Change. Direct planting system is largely used in the country to avoid tilling and soil disturbance and thus loss. The official plan ensures credit for projects adopting this technology (BRASIL 2012, cited by Alves et al., 2017). Until 2018, 52 million hectares had been benefitted by this plan and 115% of the goal was accomplished. Also, 170 million Mg CO$_2$ eq. were mitigated (Manzatto et al., 2020).

In April 2021, the Brazilian Government launched another program called Plan ABC+ from now on called “Brazilian Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+)” (Mapa 2021). This is an amplified wider strategy than the ABC plan. The government estimates that by 2030, low carbon emission agricultural practices will have been adopted by 52 million hectares.

Another approach is a seal that was developed called the “regenerative livestock production seal” which is a set of sustainable practices as a production model which revitalizes the system producing an environmental surplus instead of an ecological deficit (O Agro pode mais 2021). Thus, to obtain this seal, the cattleman has to observe the recommendations of the soil specialist in order to fix carbon instead of emitting it.

Another government program in Brazil is the technological concept brand called “Carbon Neutral Brazilian Beef” (Carne Carbono Neutro - CCN, in Portuguese) developed by Embrapa in 2015. The concept is represented by a label referring to beef cattle produced under integrated systems with mandatory presence of a forestry component. This concept aims to support implementation of more sustainable cattle systems, especially regarding environment, through introduction of trees that are able to neutralize emissions of methane by cattle. It ensures added value for beef produced under such systems. In short, to receive and use the “Carbon Neutral Beef” seal, the final product (beef and its derivatives) must comply with all the prerequisites and parameters inherent to the general concept established (Alves et al., 2017).

Following the line of mitigation of GHG emissions, in 2020 Embrapa launched the Low Carbon Brazilian Beef concept brand, to value beef produced in livestock systems based on good agricultural practices and sustainable intensification, however, without the presence of the forestry component in the productive area (Almeida and Alves 2020). At the same time, many beef processing industries in Brazil are rejecting cattle from farms with pending issues such as from deforestation areas, indigenous land, areas embargoed by the government, environment conservation areas or that contain a history of slave work.

According to Rao et al. (2015), sustainability also implies on lifestyle choices involving changes to the production and consumption systems, thus, sustainable intensification involves social transformation. A very good example of social transformation resulting from technology adoption is the case study in Brazil, of a program called ‘Balde Cheio’ (translation Full Bucket).

The ‘Balde Cheio’ Program (Full Bucket) in Brazil was selected as one of Embrapa’s technological solutions aligned to the Sustainable Development Goals referring to poverty eradication, decent employment and economic growth (O agro pode mais 2021). The program is a technology transfer methodology that aims to train technical assistants, rural extensionists and cattlemen to expand milk production and create an alternative income for small and medium-sized rural producers.
(Embrapa 2021). The program was initially based on well-managed and fertilized Mombaça pastures (guineagrass cultivar Mombaça released by Embrapa in 1993 -Jank 1995), and on existing pastures in good conditions with the indications the project team furnishes.

By this program, one property per county (must be over 0.5 ha area, be a family enterprise and focused on dairy) is selected by the trained technician to serve as a reference for other producers in that region. After approval by the project team, the owner must answer a questionnaire that will identify the production system, the socioeconomic situation of the family, and environmental issues. The property receives the technical assistance of the trained technician for four years and theoretical classes. For the property to be used as a classroom and a reference to that county and to continue receiving the benefits of the program, the producer has to execute everything exactly according to the guidelines and to what was agreed upon (Sebrae 2021).

The case study involved 1,609 properties in 468 counties in 19 Brazilian states assisted by the program (O Agro pode mais 2021). The results showed that the program generated an increase in the producers’ revenue by 2.3 times, in addition to raising the quality of life of the rural and urban populations. Milk production increased 43%, while occupied area decreased 7% and workforce performance improved 37%, resulting in an almost double average gross margin per hectare. However, one of the main positive effects, not perceivable in the statistics, was the rescue of the self-esteem of small-scale milk producers, and rural extension technicians, who now have decent incomes and better living conditions for the whole family. Also, more jobs were created and more people were fixed in the country, especially the young generation.

Due to the success of this program, this methodology is now being adapted to other specific conditions, as milk production from goats, buffaloes, and for beef cattle (O agro pode mais 2021).

Another successful initiative for improvement of the efficiency of the productive system due to technology is the Young Steer Program (Programa Novilho Precoce) (Bungenstab 2012). This program, together with the Protocol of ‘Good Agricultural Practices: Beef Cattle’ (Valle 2011) established a set of standards and procedures that must be adopted by the participating properties in order to receive the tax incentives offered by the Government of the State of Mato Grosso do Sul. This, not only allowed farmers to achieve increased productivity and sustainability of the activity, addressing social, labor, productive and environmental aspects, but also became an important and relevant management tool to meet the growing demand for safe food and consolidate Brazil as the world’s largest producer of beef from sustainable production systems.

**Forage Germplasm**

In temperate climates, there is a continuous release of forage cultivars based on solid, well established breeding programs and there are many programs based on the same species in different countries. Also, the number of different species studied and Young Steer Program bred is small. In tropical countries, however, there are very few and recent programs and in only a few countries, because breeding is only at its infancy. But the number of species of forage worth breeding is very large. Maass and Pengelly (2019) reported that around 160 worthy species were included in the Tropical Forages database of CIAT (https://www.tropicalforages.info/text/intro/index.html), and even if 50% are of limited forage value, the numbers are still very large.

Almost 182,000 accessions of more than 1000 species of grasses, legumes and fodder trees have been collected worldwide both from tropical and temperate regions (Figure 3). These are maintained in 80 national and international genebanks registered in Genesys (www.genesys-pgr.org) (Hanson and Ellis (2020). Despite the large genetic diversity, both within species as well as in terms of species numbers with forage potential, the germplasm conserved in these banks are underutilized and unexplored in the forage breeding programs.

On the other hand, Maass and Pengelly (2019) expressed concerns that around 60% of the conserved accessions in the two International Centres (CIAT and ILRI) have limited forage value. Thus, efforts dispended in the conservation of these accessions are constantly being reviewed and discussed, since conservation is very costly especially if these resources and not being explored.
Nevertheless, efforts in germplasm conservation are important, especially if the breeding programs use the germplasm and if new accessions are constantly being incorporated into the program. To deal with this and since seed storage is still the most cost-effective and efficient method for forage conservation (Hanson and Ellis 2020), Pengelly and Maass (2019) presented many suggestions on how the use and conservation of these forage accessions should be dealt with based on improved efficiency, effectiveness, awareness and collaboration that should be adopted urgently. Efficiency could be attained by implementing taxa priorities and losing the lowest priority germplasm; by developing core collections and eliminating duplicates, triplicates etc. More efficacy could be attained by fitting the best existing genotype into targeted agro-ecological niches and production systems. This requires the expertise of conventional breeders and former germplasm specialists, which invest in field observations and descriptive assessment, and not only about applying the latest technologies by younger generation of researchers. Increase seed supply is also suggested to supply greater quantities of well-adapted elite material, for increased evaluation and utilization. And last, increased awareness and knowledge of other forage evaluation and utilization elsewhere. To help with this issue The Tropical Forages Database is available (https://cgspace.cgiar.org/handle/10568/49072), as well as the excellent newsletters produced by Maass and Pengelly (2016-2019).

Figure 3. Worldwide forage collection sites. Source: Hanson and Ellis (2020).

Forage Breeding

Through breeding, many characteristics can be improved which result in higher sustainability for improved livelihoods. The first characteristic is yield, which based on large germplasm resources is the easiest to be improved. Through time, improved yields have been obtained in most forages. In temperate climates, 4% to 5% increases in yield have been reported per decade in perennial ryegrass (Lolium perenne L.) breeding [Wilkins and Humphreys (2003) cited by Kingston-Smith et al. (2013)]. However, yield of cultivars of smooth bromegrass (Bromus inermis Leyss.) developed between 1942 and 1995 did not change (Casler et al., 2000).

In tropical forages, however, breeding is still a very recent activity, thus large gains in yield may still be observed. Based on the germplasm collected in the Centre of Origin of Megathyrsus maximus (syn. Panicum maximum) and transferred to Brazil in the early 1980s (Savidan et al., 1987), leaf dry matter yields of the first two cultivars released, Tanzânia-1 in 1990 and Mombaça in 1993, were respectively 86% and 136% greater than cultivar Colonião in use at the time (Jank 1995). Further large increases in yield, as these presented, either through selection within the germplasm or through breeding may hardly be expected, however new challenges to the breeder are constantly forthcoming such as resistance to pests and diseases, tolerance to waterlogging and dry spells among others, as mitigation and adaptation strategies in a climate change scenario.

Other characteristics include nutritive value, with increased protein and digestibility, which will have a direct effect on decreasing GHG emissions
by the cattle. Thus, increased quality of the forage will contribute to mitigate climate changes (Euclides et al., 2010; Eugène et al., 2021). New cultivars bred for increased tolerances/resistances to both biotic and abiotic stresses will also contribute to an increased sustainability. Table 1 shows the main characteristic improved in some of the released forage cultivars in Brazil which contribute to an increased sustainability. Accessions found in germplasm banks may be excellent sources of tolerance and resistance to many sources of diseases and pests, as well as to increased quality and yield in tropical forages.

**Table 1. Improved forage species in Brazil and the main characteristics improved.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Cultivar</th>
<th>Cultivar compared</th>
<th>Main Characteristic improved *</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. maximus</em></td>
<td>Tanzânia</td>
<td>Colonião</td>
<td>24% &gt; ADG</td>
<td>Euclides et al., 1999</td>
</tr>
<tr>
<td><em>M. maximus</em></td>
<td>Mombaça</td>
<td>Colonião</td>
<td>136% &gt; LDMY</td>
<td>Jank, 1995</td>
</tr>
<tr>
<td><em>M. maximus</em></td>
<td>BRS Tamani</td>
<td>Massai</td>
<td>49% &gt; ADG</td>
<td>Braga et al., 2019</td>
</tr>
<tr>
<td><em>M. maximus</em></td>
<td>BRS Quênia</td>
<td>Tanzânia</td>
<td>32% &gt; ADG</td>
<td>Andrade et al., 2013</td>
</tr>
<tr>
<td><em>M. maximus</em></td>
<td>Massai</td>
<td>Colonião</td>
<td>53% &lt; seasonality of production</td>
<td>Embrapa Gado de Corte, 2001</td>
</tr>
<tr>
<td>Brachiaria brizantha</td>
<td>BRS Xaraés</td>
<td>Marandu</td>
<td>20% &gt; Animal Production</td>
<td>Valle et al., 2004</td>
</tr>
<tr>
<td><em>B. brizantha</em></td>
<td>BRS Piata</td>
<td>Marandu</td>
<td>7% &gt; Live weight gain</td>
<td>Valle et al., 2007</td>
</tr>
<tr>
<td><em>B. brizantha</em></td>
<td>BRS Paiaguás</td>
<td>Piata</td>
<td>8% &gt; ADG in the dry season</td>
<td>Euclides et al., 2016</td>
</tr>
<tr>
<td>Brachiaria hybrid</td>
<td>BRS Ipyporã</td>
<td>All others</td>
<td>&gt; Resistance to spittle-bugs</td>
<td>Valle et al., 2017</td>
</tr>
<tr>
<td>Pennisetum purpureum</td>
<td>BRS Capiaçu</td>
<td>Cameroon</td>
<td>66% &gt; TDMY</td>
<td>Pereira et al., 2017</td>
</tr>
<tr>
<td><em>P. purpureum</em></td>
<td>BRS Kurumi</td>
<td>Mott</td>
<td>56% &gt; LDMY</td>
<td>Pereira et al., 2017</td>
</tr>
<tr>
<td><em>Andropogon gayanus</em></td>
<td>BRS Sarandi</td>
<td>Planaltina</td>
<td>14% &gt; LDMY</td>
<td>Carvalho et al., 2021</td>
</tr>
<tr>
<td><em>Stylosanthes spp.</em></td>
<td>BRS Campo Grande</td>
<td>Mineirão</td>
<td>Seed production</td>
<td>Embrapa Gado de Corte, 2007</td>
</tr>
<tr>
<td><em>Stylosanthes guianensis</em></td>
<td>BRS Bela</td>
<td>Mineirão</td>
<td>Seed production and clay soils adaptation</td>
<td>Embrapa Gado de Corte, 2019</td>
</tr>
</tbody>
</table>

*LDMY = Leaf dry matter yield; SDMY = Stem dry matter yield; TDMY = Total dry matter yield; ADG = Average daily gain per animal

Hanson and Ellis (2020) presented a very nice synthesis of the climate zone suitability for cultivation of the most common tropical and sub-tropical forage species. They classified the species in terms of suitability for arid, semi-arid, sub-humid, humid and highland zones. Breeding within these species, respecting their cultivation suitability will definitely improve sustainability, by increasing yield and persistence of the pastures and avoiding pasture degradation. Breeding for disease and pest resistances, and abiotic stresses, as drought and water logging tolerances are also excellent alternatives to improve sustainability for the same reasons above.

**Discussion/Conclusion**

Since Grasslands occupy about 80% of global agricultural land and as we head to more intensive climate changes, pasture sustainability is absolutely imperative. Considering the different climates, soils, herds, cattle and pasture management and both forage and financial resources available worldwide, every step taken towards a more sustainable reality is very positive and necessary. Every activity which improves pasture productivity, quality, persistence, intensification, carbon sequestration, resilience, adaptation, GHG mitigation, whilst decreasing soil degradation and demands for water use,
fertilizers, insecticides, pesticides and herbicides contribute to pasture sustainability and result in positive social, environmental and economic impacts. Thus, forage selection from natural germplasm conserved in genebanks and forage breeding to obtain new improved more efficient and adaptive cultivars, as well as management strategies to improve pasture use, and public policies all help pasture sustainability.

Different countries are creating their own policies, frequently injecting governmental resources in order to more effectively stimulate the adoption of these policies by farmers, in order to mitigate deleterious effects of animal production on pastures and probably this is the most effective way to attain sustainability. There is a worldwide discussion on consumption of red meat but the demand for this excellent source of protein in the near future will undoubtedly continue to be high or even increase. Therefore, despite the differences in consciousness levels in the different countries it is indeed imperative to improve forages and pasture management to continue to make the world a better and more sustainable place to live.

Acknowledgement

The authors would like to thank the organization of the Congress for the opportunity to share ideas and contributions to more sustainable agropastoral production. Thanks are also due to the multiple colleagues and partners, private and public in the development of new improved forages in Brazil.

References


Capacity, Institutions and Innovations for sustainable development in Rangelands/Grasslands

Dr Jonathan Davies
International Union for Conservation of Nature (IUCN)

Abstract

Rangelands occupy 54% of all land and are found on all continents. They are rich in biodiversity and simultaneously support the production of high-quality animal protein: 84% of the rangelands are used for livestock production. Rangelands provide incomes to millions of households, many of which derive income and other benefits from a combination of livestock and natural goods and services. Sustainable management of rangelands depends on understanding rangeland ecology, and specifically the interactions—positive and negative—between livestock herding and ecosystem health.

Rangelands management fundamentally revolves around the management of herds to generate specific interactions between animals and vegetation, promoting the benefits and avoiding the risks associated with grazing. Degradation of rangelands is often attributable to changes in the way herders manage their livestock, and it can be driven, amongst other things, by changes in the availability of resources (e.g. due to changes in climate or in infrastructure), changes in the presence of threats (such as diseases or insecurity), and changes in decisions made by governing institutions (e.g. through emergence of new decision-making structures or weakening of customary institutions).

Development and modernisation in most countries has affected availability of rangeland resources (e.g. more water points, more markets and other amenities, new roads, and access to imported fodder) and has influenced the presence of threats (improved security, access to veterinary services (deworming), and pest control (tsetse)). As a result, mobility is less influenced by ‘environmental’ factors and this places new pressures on institutions to determine herd movements. In many rangelands this is taking place in parallel with weakening of those institutions, creating the need for innovations in the way institutions are enabled to govern rangeland management. Rangeland restoration and sustainable land management are therefore a challenge for institutional innovation above all.

The concept of ‘sustainable land management’ in a rangeland context should begin with institutions and behaviours rather than technologies and practices. This recognises that the integrity and sustainable use of land resources and water is inextricably linked to functional traditional, local and other institutions. Furthermore, sustainable rangelands management cannot be achieved without pastoralists securing their resource rights, and specifically their management rights. Development partners can support sustainable rangelands management by fostering partnership between the public sector and pastoral communities, building legitimacy and trust, strengthening representation, ensuring equitable governance changes, and building the most relevant capacities for institutional innovation.
CONCURRENT SESSION 2

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Rangeland Monitoring and Support Systems
Positive changes in regional vegetation cover in Patagonia shown by MARAS monitoring system

Oliva, G. El¹-³ and J. Gaitan²

¹EEA INTA Santa Cruz;
²Instituto de Suelos INTA Castelar;
³Universidad Nacional de la Patagonia Austral

Key words: vegetation monitoring system, vegetation cover, rangelands

Abstract
MARAS (Environmental monitoring of arid and semiarid lands) is a vegetation and soil monitoring system in Patagonia, a 700,000 km² area in southern South America. Installed between 2008-2015 within INTA-Argentina and INIA-Chile national agricultural research institutes, it includes photographs, 500-point intercepts, 50-m canfield lines to detect patches, 10 land function observations and 0-10 cm soil samples in 458 ground sites. Data is centralized and freely accessible https://maras.inta.gob.ar. We analysed changes based in the first 255 reassessments made at 5-year intervals. At a regional scale significant changes (P<0.05 paired T test) were detected for: perennial vegetation cover, that was originally 42% and increased +3.1%. Plant species richness of 13.7 species/monitor increased +0.7, bare soil of 35% decreased -7.9%. Length of bare soil interpatches was 157 cm and decreased -42 cm. Land function indexes of Stability 46.2%, Infiltration 45.1% and Recycling 31.0% showed small non-significant changes (-1.3, +0.7 and +1.42 respectively). Significant changes in soils under vegetated patches were: conductivity 0.59 dS/m increased +0.49, and pH 7.3 +0.33. Organic matter was 2.0% and increased 0.35%, and sand was 73% and increased 3%. Finer soil particles decreased non-significantly. Bare soil interpatches had 1.4% organic matter and also increased 0.33%, and clay, that initially was 9.3% reduced -2.3%. The long-term ground sites provide a means to monitor slow changes in these rangelands in relation to global climatic change and regional grazing patterns. Patagonia has currently the lowest domestic stocking rates of the last century and vegetation seems to be slowly growing in perennial cover, with significant reductions in exposed bare soil, increase in biodiversity and soil organic carbon.

Introduction
Drylands are distributed over 100 of the world’s nations, comprise about 45% of the earth’s land total area, and are highly prone to land degradation and desertification. Patagonia, with 624,500 km² in southern Argentina and Chile, is mostly drylands (Gaitán et al., 2020) and has been heavily degraded in the last century due to the introduction of domestic animals at high stocking rates (Del Valle et al., 1998). The region has been de-stocked in the last two decades, and this could drive a slow regional recovery of vegetation, but climate change and the increases in aridity associated with it are expected to interact also, driving losses in vegetation cover, biodiversity and key soil properties such as soil carbon content, features that influence the functioning and capacity of these drylands to provide essential ecosystem services. In order to describe changes in these vast areas, a network of field-based observations over regional scales that encompass different ecosystem types and measures variables such as plant cover, species richness and indicators of soil fertility and indicators of Landscape Function is necessary. The task requires cooperation of scientific teams specialized in different ecosystems and working in diverse institutions. The MARAS (Spanish acronym for “Monitoreo Ambiental de Zonas Áridas y Semiaridas” or “Environmental Monitoring of Arid and Semi-arid Regions” in English) network is a field-based ecosystem monitoring protocol developed by the National Institute of Agricultural Technology of Argentina (INTA, https://www.argentina.gob.ar/inta), which has also been adopted by the National Institute of Agricultural Research of Chile (INIA, http://www.inia.cl/). Development of this methodology started in 2002 with funding of Global Environmental Funds, Project GEF Patagonia PNUD ARG07/G35 and have subsequently been funded by different Argentine institutions and projects. In Chile data has been contributed by the INIA Kampenaike
node and funded by Ministerio de Agricultura through Project 502093-70 Sistemas de Praderas Estepáricas de Zonas Frías de Chile. Formal setup of the MARAS network of monitoring plots started in 2007, and 426 monitoring plots have been surveyed until December 2019 (Fig. 1), distributed along an area with vegetation that ranges from shrublands to grasslands and semi-deserts. Re-evaluation in a 5-year cycle of the 436 monitoring plots is currently in progress, and 255 monitoring plots have been assessed twice. In this paper we analyse changes that the main variables show across the region.

Materials and Methods
Monitoring plots (426) were chosen to represent ten biozones (Oliva et al., 2019). They were progressively placed in the period 2007-2014 in uniform areas representative of dominant vegetation types, under the usual management: grazed by sheep, cattle or goats, or native Lama guanicoe (guanacos). A manual describing in depth the protocol is available (Oliva et al., 2011). Each monitoring plot consisted in three 50-m transects (Fig. 2) positioned between permanent poles in which vegetation and soil variables were recorded and reassessed ideally every five years. Vegetation was sampled using two 50-m line transects with 250 interception points each, and patch structure was sampled with 50-m gap intercept lines for interpatches (areas that lose resources, minimum length 5 cm) and patches (resource sink areas, minimum length 10 cm). Soil stability, infiltration and nutrient cycling were assessed using 11 soil superficial condition indicators recorded in ten bare soil patches following the Landscape Function Analysis (LFA) methodology (Tongway y Hindley 2004). Two 0-10 cm depth composite soil samples were obtained, one from patch and one from interpatch areas, which were analysed in laboratory for pH 1:2.5, conductivity (dS/m), Organic matter / Walkley - Black (%), Total N Kjeldahl (%) and texture was obtained using a using Bouyoucos hydrometer. All data was entered in a database that was developed by the National University of Austral Patagonia (UNPA) and is freely accessible via https://maras.inta.gob.ar/portal/app/index.php. Data has also been deposited in an international database in the Figshare public repository (Oliva et al., 2020). In the period 2015-2019, 255 of these monitoring plots were reassessed after a period of 6.3±1.7 years and we compared key indicators of vegetation and soil using paired T test.

Results
Location of monitoring plots
Figure 1: Left: Map of the MARAS network in Patagonia as of September 2019. Dots represent monitors: those in blue have been surveyed twice, red ones have surveyed only once. Right: Diagram of the monitoring plots based on permanent steel poles. Three 50-m transects were surveyed using graduated tapes and ropes were used to outline the trapezoid - shaped photographic plot. All tapes and lines were removed after assessment.
Assessment of change

The 255 reassessments showed significant changes (P<0.05 paired T test) for: increase in perennial vegetation cover (%), plant species richness (number of species), decrease in bare soil (%) (Fig. 2). The mean length of bare soil interpatches was 157 cm and decreased -42 cm (data not shown). Land function indexes of Stability, Infiltration and Recycling showed small non-significant changes (Fig. 2). Laboratory soil analysis for vegetated patches showed significant increases in conductivity, pH, Organic matter, and sand % (Fig. 2). Finer soil particles decreased non-significantly. Bare soil interpatches had 1.4% organic matter and also increased 0.33%, and clay, that initially was 9.3% reduced -2.3% (data not shown).

Discussion

Changes observed indicate that vegetation cover at regional scale in Patagonia significantly increased in the period 2014-2019. Bare soil was reduced and a small but significant increase in diversity, evaluated through species richness has also been found. The main Land Function indicators remained without significant changes. This increase in vegetation cover is the result of a complex interaction between climate, as both dry spells and favourable periods were experienced in this vast region, and the effects of improved management with lower sheep stocks and farm abandonment, as regional sheep stocks that reached 20 M in the 1950’s fell to 7 M in the last two decades. Soils show an increase in sand, that probably reflects on-going erosion of the finer particles of loam or silt in this region subjected to intense wind storms. Total Nitrogen did not vary and the tendency to increase pH and conductivity is hard to explain. A positive trend in organic matter accumulation of 0.34% that demonstrates that the region is acting as a carbon sink, and could offset the CO2 equivalent emissions of the sheep industry. As a conclusion, Patagonia is apparently recovering from past degradation, and the MARAS monitoring network provides hard data that should be further analysed in combination to remotely sensed data and at a biozone scale to interpret changes and intra-regional trends.

Acknowledgements

We want to acknowledge field and database work of Virginia Massara, Guillermo García Martinez, Cecilia Caruso, German Cariac, Daniela Echevarria, Anabella Fantozzi, Lucas Butti, Donaldo Bran, Daniela Ferrante, Paula Paredes, Erwin Dominguez, Fernando T. Maestre and Fernando Umaña. Database was designed by Eder Dos Santos and Osiris Sofia.
References


EcoRestore: Decision Support System to restore the productivity of degraded rangelands in southern Africa

Kellner, K.¹, Pretorius, D.² and Marais, C.³.

¹School of Biological Sciences and Unit for Environmental Sciences and Management (UESM), North-West University, Potchefstroom, South Africa
E-mail: Klaus.Kellner@nwu.ac.za
²Professional GISc practitioner, SMC Synergy, Pretoria, South Africa
E-mail: dirk@smc-synergy.co.za ³Chief Director, Natural Resource Management Programme, Department of Environment, Forestry and Fisheries, Cape Town, South Africa
E-mail: CMarais@environment.gov.za

Key words: land degradation; bush encroachment; decision support system; rangelands.

Abstract
Land degradation is a multifaceted problem that affects the agricultural productivity of land due to a loss of vegetation cover. It can often be ascribed to bush encroachment in savanna and grassland rangelands. Bush encroachment entails the increase in abundance and density of indigenous and alien woody vegetation (i.e. shrub thickening), which has a negative impact on the tree-grass ratio, biodiversity, as well as on a range of ecosystem services that affect the well-being of land users, often causing an increase in poverty and the introduction of non-sustainable land management practices, especially in arid- and semi-arid regions mostly affected by climate change. In response, the North-West University, in collaboration with the Natural Resource Management (NRM) programme of the South African Department of Environment, Forestry and Fisheries (DEFF) and consultants, developed the Bush Expert Information Management System (BEIMS) that will help land users to make scientifically sound decisions regarding the restoration/rehabilitation and sustainable management of degraded land. The core components of the BEIMS are the EcoRestore Decision Support System (DSS) that contains guidelines for restoration after bush control and the Bushmon database that contains information (including spatial location) of bush encroachment restoration research projects. The BEIMS (abbreviated as Bush Expert) is a cloud-based, easily accessible online system that can also be linked to a standalone Global Information System via a spatial database link. Stemming from the BEIMS, the EcoRestore DSS can provide scientifically assessed information on projects where restoration technologies have been applied – including aerial photography that track the before and after successes of restoration/rehabilitation processes. To follow is a discussion of the results of a number of restoration applications derived with the aid of BEIMS, with due consideration for the current functionality and accessibility of the system.

Introduction
Land degradation (LD) is a worldwide phenomenon in drylands, negatively impacting agricultural productivity and ecosystem services and the livelihoods of many people, especially those living from the land (MEA 2005; Hoffman and Ashwell 2001). A multitude of factors has been identified as the drivers of LD in rangelands (Kgosikoma and Mogotsi 2013; O’Connor et al., 2014), which include climate change, certain land-use practices in different land tenure regimes, over-grazing, the invasion of alien plants, loss of topsoil through erosion (wind and water) and the loss of biodiversity (Von Maltitz and Evans 1998; Ward 2005). Land degradation leads to an increase in woody density (shrubs and trees), causing an imbalance in the tree-grass ratio, which leads to bush thickening (BT) (increase in density of woody species already occurring in the region) and/or bush encroachment (BE) (increase in density and invasion of woody species not occurring in the region) (De Klerk 2004). In addition, due to competition for soil moisture, vegetation cover – especially grasses decreases, ultimately reducing fodder production for grazing animals in savanna rangelands (Von Maltitz et al., 2019). Bush encroachment/thickening is regarded as one of the most extensive forms of LD in arid and semi-arid rangelands, causing biome shifts from...
open savannas to closed woodlands and altering the functions and biodiversity of the original savanna by reducing the economic benefits of the rangelands (O’Connor et al., 2014; Eldridge et al., 2011).

Recent studies conducted by Turpie et al. (2019) and Warren et al. (2018) found that BE affects around 7.3 million ha of the land area in South Africa, especially in grassland and savanna biomes which, respectively, comprise around 27.9% and 32.5% of the land surface area.

A number of technologies have been implemented by land users as well as private and government organisations to control the increase in woody density and increase vegetation cover of palatable, climax grass species in attempts to improve fodder production and grazing capacity (Harmse 2013; Harmse et al., 2016; Kellner et al., 2021; Joubert et al., 2014; Lukomska et al., 2014; Smit 2004).

In response to these studies, Turpie et al. (2019) recommended that information and advisory service be established to, amongst others, offer guidelines for the management and that, secondly, further research should be conducted to determine the biodiversity impacts of BE, the potential effects of woody biomass removal on soil fertility and the possible role of woody cover in restoring degraded soils.

Subsequently, the North-West University (NWU), in collaboration with the Natural Resource Management (NRM) programme of the Department of Environment, Forestry and Fisheries (DEFF) as well as several consultants, developed the Bush Expert Decision Support System (DSS). Also resorting under this system is the EcoRestore Expert System that contains information on restoration after bush control.

The EcoRestore DSS maintains a database that includes case studies of technologies and approaches that have been researched and applied by rangeland managers, scientists and farmers over the short and long term in an attempt to restore/rehabilitate degraded rangelands or to combat the problem of BE and alien species invasion (Barac 2003; Barac et al., 2004). Primarily, the DSS intends to optimise the exchange of knowledge concerning practices to restore/rehabilitate degraded rangelands that have been applied previously and disseminate this to as many users as possible for future rangeland management applications. Currently, the case studies in the DSS mainly cover technologies captured in studies conducted in Namibia (Barac 2003). It is, however, envisaged that case studies from other Southern African Development Community countries, including South Africa, will be included within the near future.

Development of the EcoRestore DSS

Initially, EcoRestore DSS was developed as an online application in 2003, at which time it was also made available as a CD-ROM (Barac 2003). The online version was hosted by the NWU and did not include a spatial database platform. Currently, an improved version of EcoRestore DSS as a component of the Bush Expert Information and Management System (BEIMS) is being re-engineered in three phases (Figure 1). Even though BEIMS is still in a developmental stage, it can be accessed via two websites, i.e. www.beims.co.za and www.bushmon.co.za. Note, though, that to access all BEIMS functions (databases, maps, etc.), registration and a password will be required.

![Figure 1: Steps in the development of the Bush Expert Information Management system (BEIMS), with the inclusion of EcoRestore DSS and Bushmon modules.](image-url)
The map viewer interface of BEIMS was developed in Leaflet, an open-source JavaScript library for interactive web maps. It is lightweight, simple and flexible and is probably the most popular open-source mapping library.

The use of the Leaflet map viewer allows the integration of various base map sources (e.g. Bing and Google maps), user-created spatial data (e.g. EcoRestore and Bushmon case studies and projects) as well as links to Web Map Service data sources (e.g. ESRI farm portions and digital aerial photographs).

As mentioned, the development of Phase 3 will commence shortly and focus on finalising all data capturing fields and information for drop-down menus. All modules - including multi-temporal capabilities – will be available on the internet and as a mobile application (app).

The Bush Expert DSS and BEIMS can be used to identify the best technologies to restore the ecosystem functions and services of degraded land, especially after attempts have been made to control bush encroachment. BEIMS will help land users, land managers and policymakers to make scientifically sound decisions regarding restoration/rehabilitation and sustainable land management (Mangani et al., 2020; Sebitloane et al., 2020)

Acknowledgements
The NWU and partners would like to thank the South African Department of Environment, Forestry and Fisheries for its financial and other support.

References


Von Maltitz, G.P. & Evans, J. 1998. Is tenure the root cause and consequently the solution to resource degradation in the communal areas of rural South Africa? In Proceeding of the International Conference on Land Tenure in the Developing World, organised by the University of Cape Town, Cape Town, South Africa.


Enhanced grazing management assessment using drone-based lidar measurements

Temu, V.W.¹; Hession, W.C.²; Sforza, P.³; Wang, H.³.

¹Agricultural Research Station, Virginia State University; ²Biological Systems Engineering, Virginia Polytechnic Institute & State University
³Center for Geospatial Information Technology, Virginia Polytechnic Institute & State University

Key words: biomass, drone, forage

Abstract
Globally, there is an urgent need of research-based technologies for small ruminant producers to benefit from rapidly growing market demands for ruminant meat and related food products from forage-based operations. However, effective forage-based animal production requires a rapid assessment, and monitoring of grazing management needs to adjust stocking rates and/or spatial animal distribution in a timely manner. Applicability of unmanned aerial vehicles (drones) for grazing management offers opportunities to rapidly estimate biomass build-ups, ground coverage, and monitor animal behaviour. The reliability of drone-based laser scanning (DLS) for monitoring warm-season grass responses to simulated grazing intensities was assessed at Virginia State University. Aerial DLS point-cloud data were collected from pure and mixed native warm-season grass stands at early- and mid-season post-harvest regrowth in early May and June, respectively, along with ground-based estimates of yield and ground cover. Animal behavioural responses to drone activity at different heights were also recorded. The aerial estimates from DLS point cloud characteristics were compared with matching ground-based measurements of forage biomass, sward heights, and ground cover. Discernible correlations between the point cloud-based estimates and actual measurements for forage biomass, ground cover and sward heights were observed. Goats showed no changes in activity due to drone flights at ≥15 m above ground but demonstrated curiosity to drone presence between 10 and 15 m. These preliminary results suggest reliable applicability of DLS for expedited assessment of plant and animal responses to grazing management.

Introduction
Precision agriculture technologies enable managers to quickly establish current plant growth problems, such as lodging for maize (Zhou et al., 2010), and take appropriate measures to improve or sustain productivity on specific areas. Likewise, effective management of forage-based animal production requires informed decisions on specific plant and animal responses to changes in environmental conditions that affect yield and quality. In grazing management, this includes the rapid assessment of plant growth responses to biomass removal, specific fertility management needs, and necessary changes to stocking rates or supplemental feeding. Other necessary components of ecological pasture management include concurrent monitoring of soil moisture and health, and greenhouse gas emissions. The advents of unmanned aerial vehicles (UAVs), or drones, with various sensors, offer technological alternatives to conventional monitoring of vegetation dynamics (biomass build-up, phenology, ground coverage, weed challenges), as well as grazing preferences and behaviour (Lu et al., 2019). However, the suitability of recent laser scanning or Light Detection and Ranging (lidar) sensors as payloads on drones is uncertain due to the scarcity of research studies related to the efficacy of their use in agriculture.

Lidar uses pulsed laser reflected off remote surfaces to measure distances (or ranges) from the instrument, and generate precise, three-dimensional information about these surfaces. The lidar provides detailed mappings of land surfaces and the vegetation height, canopy structure, standing biomass, etc. (Howell et al., 2020). In managed forests, our research team has utilized a drone-based laser scanning (DLS) system for such vegetation measurements, successfully, to include creating high-resolution flood inundation maps and roughness at different flood stages due to vegetation (Resop et al., 2019). However, information on detailed measurements with lidar
for the purposes of improving forage management is scarce. This study was, therefore, designed to (i) assess the reliability of DLS for estimating tall-grass responses to simulated grazing and (ii) monitor the response of small ruminants to drone activities on pasture. The study compared drone-based forage data to conventional on-the-ground sward-height and forage biomass measurements with respect to forage production and growth response to intensity of defoliation, as well as likely flight-height effects on animal behaviour.

Materials and Methods

Study Site

The study was conducted on 160 (7 × 6 m) plots of native warm-season grasses separated by ≥3 m alleys at Virginia State University research farm in Chesterfield County, Virginia (37° 13’ 43” N; 77 º 26’ 22” W, 45 m above sea level). Each research plot was subdivided into four parallel harvest strips (1.2 m wide) that had received three-, two-, one-, or zero-cuts in a growing season over three consecutive years. In mid-April, the research area had the outermost plot-margins marked out on a google-map and flight-patterns for eight overlapping fly-overs were set. On May 1, and June 4, Aerial imagery and point-cloud data were collected using a DLS system that consists of two primary components: (1) the drone system (Pulse Aerospace Vapor 35) and (2) the lidar system (YellowScan Core System Mapper). The Vapor 35 drone is a helicopter-style UAV that can be mounted with remote sensing devices like lidar and has a maximum hover time of 45 min. The YellowScan Core System Mapper is an ultra-light lidar system that is integrated with the Vapor 35. The YellowScan lidar system contains embedded GNSS, IMU, and computer. Up to two discrete returns are recorded for each lidar pulse produced by YellowScan. At a flight elevation of 20 m, a DLS is point density of 455 points m⁻² is reported (Resop et al., 2019). Matching actual sward-height measurements, ground cover estimates, and late-summer plot forage biomass records were also collected. Whole-field aerial-view photos were also taken over the research plots and adjacent grazing paddocks stocked with goats. To assess effects of the drone-activities on goat behavior, a series of still aerial-view photos of the goats on pasture were taken as the flight-height decreased from 20 m down to slightly below 10 m above ground. Animal responses to the drone activities were remotely monitored using a 3D Visual Reality head set that allowed for close views while physically away and to instantaneously signal for the pilot to take descriptive photos.

The flight row data were processed into LAS format (one designed for the interchange and archiving of lidar point cloud data) and analyzed for the plant parameter estimates and 3D visualization. Late-summer forage harvest was done using a plot harvester equipped with a weighing system for on-site fresh weight records. Fresh samples of the harvested material were also collected from each strip and weighed before and after oven-drying to constant weight at 65°C to determine moisture content at harvest and convert the plot weights into forage dry matter (DM). The resulting drone-based biomass estimates (kg DM ha⁻¹) and their matching actual measured forage yield from respective harvest strips were then organized into a dataset on a spreadsheet and statistically analyzed using the Random Forest (Breiman et al., 2018) and Multiple Regression to establish their predictive powers. From the point cloud data, classified color images were also developed showing ground elevation and grass details in field cross-section views of plots in a row and cut-strips within a plot.

Results

Lidar and Vegetation structure

The results of drone-based aerial view of the research plots (Figure 1) shows the ground elevation as gently sloping North-West (left-top) to South-East (bottom-right). The layered points cloud output separated below shows differences in sward heights across the field and distinctive plot alleys. From the same data, single-plot vegetation details (not included) showed discernible patterns of sward-heights for different harvest-strips and separating alleys. The classified colour images could also be presented separately with desired details of each attribute. Based on the drone-captured still photos at different heights over the adjacent grazing paddocks, goats were not disturbed by the drone activities when 15 m or higher above ground. Below 15 m the goats showed curiosity to the drone but still did not appear disturbed. With the drone flying just below 10 m above ground, however, few goats that were resting on pasture got up and became more attentive and ready to move.
**Figure 1:** Classified colour images of 160 native warm-season grass plots in three rectangular clusters (L-R), from June-4 drone-based point-cloud data showing plot lay-out, vertical elevation (top plate; red for high- & blue for low-ground) and field cross-section vegetation details (bottom).

**Forage Biomass Estimates**

Statistical analyses comparing the measured forage biomass to their matching drone-based estimates (Figure 2) indicated stronger correlations when run through the Random Forest model than the multiple regression. For both models, the predicted forage biomass was closer to the actual measured value for the single-cut strips than their three-cut counterparts and in-between for the two-cut ones. For the three-cut strips, the Random Forest model tended to overestimate the actual forage biomass at higher harvest weights.

**Figure 2:** Late-summer forage biomass (kg DM ha$^{-1}$) of native warm-season grass strips that previously received one- (top), two- (middle) or three-cuts (bottom) a season, as harvested (x-axis) or drone point-cloud data predicted (y-axis) by Random Forest model (left) and Multiple Regression (right). Proportions of weed plants were greater in the three-, but none in the one-cut strips.
Discussion and Conclusions

Although not analysed, similar result patterns were assumed for the zero- as well as the one-cut strips. However, consistent with their taller swards, higher forage biomass values were also expected. The observed weaker correlation between the measured and predicted forage biomass for the three-cut strips may have resulted from inconsistencies in the proportions of weeds, shorter than the cutting height, that were not reflected in the point-cloud data. The time lapse from the drone-flights and actual harvest dates also allowed for inconsistent changes in harvestable weed biomass as some matured and lodged below the cutting height while others expanded to cover voids between the perennial grasses. Overall, these results still indicate a dependable suitability of DLS technologies for real-time monitoring of plant and animal responses to grazing management. The demonstrated ability to closely predict the forage biomass will also be helpful for timely adjustments to specific stocking densities and grazing duration or feed supplements.

Acknowledgements

This study was financially supported by the United States Department of Agriculture – Evans Allen program and the Institute for Critical Technology and Applied Sciences at Virginia Tech while the management of the Agricultural Research Station at Virginia State University provided land and material support for the research. Our UAV pilots were Laura Lehmann and Brittany Grutter with students Lauren Wind and Charles Aquilina (Virginia Tech) and Areal Coleman (Virginia State University) helping with data collection and processing.

References


THEME 1: RANGE/GRASSLAND ECOLOGY

Topic : Rangeland Degradation and Restoration
C \textsubscript{3} perennial grass dominates mixed C \textsubscript{3}/C \textsubscript{4} grasslands after invasion by a C \textsubscript{3} woody sprouter

Cooper, C.E.\textsuperscript{1}; Ansley, R.J.\textsuperscript{2}; Steffens, T.J.\textsuperscript{3}; Murray, D.B.\textsuperscript{4}; Zhang, T.\textsuperscript{5}

\textsuperscript{1}Natural Resources Management, Texas Tech University, Lubbock, Texas, USA; \textsuperscript{2}Natural Resource Ecology and Management, Oklahoma State University, Stillwater, Oklahoma, USA; \textsuperscript{3}Agricultural Sciences, West Texas A&M University, Canyon, Texas, USA; \textsuperscript{4}Wildlife, Sustainability, and Ecosystem Sciences, Tarleton State University, Stephenville, Texas, USA; \textsuperscript{5}Texas A&M AgriLife Research, Vernon, Texas, USA

Key words: Prosopis; Nassella; C \textsubscript{3} mid-grass; C \textsubscript{4} mid-grass; woody encroachment

Abstract

Honey mesquite (Prosopis glandulosa) encroachment has resulted in decreased C \textsubscript{3} mid-grass production and increased C \textsubscript{4} mid-grass in the Southern Great Plains of the US. Woody legumes have had similar effects in Africa, Australia, and South America. Prosopis initially facilitates Texas wintergrass (Nassella leucotricha) growth under canopies, in part because N-fixation by this woody legume enriches subcanopy soils, favoring C \textsubscript{4} species. As stand density increases, Nassella extends into interspaces between trees as well. Here we report Nassella responses in several studies that either reduced Prosopis to indirectly impact Nassella or treated Nassella directly. In a 9-year study following mechanical top-kill of Prosopis, Nassella increased production for the first 3 years before slowly declining to pre-treatment levels. C \textsubscript{3} mid-grass production increased, but was limited to only a third of its potential by drought and Prosopis regrowth. Following a root-killing treatment of Prosopis, Nassella production and total herbaceous production were greater in treated than untreated intercanopy and subcanopy microsites 1-yr post-treatment. Nassella and perennial grass production declined in treated microsites 2-yr post-treatment; however, total herbaceous production remained greater in treated than untreated microsites due to increased annual forb production. Targeted grazing reduced Nassella cover and reproduction, but increased bare ground. Multiple-stemmed Prosopis with low-hanging limbs protected Nassella, thus limiting targeted grazing success when trees were not removed. The Prosopis/Nassella state appears to be resistant to change and may permanently limit transition back to C \textsubscript{4} grassland unless Prosopis is root-kill, though our results indicate that even root-killing Prosopis does not guarantee an immediate increase in C \textsubscript{3} production. If so, managing Prosopis height and canopy cover, C:N ratios of the vegetative layer, and grazing Nassella during peak production and nutritional quality may allow profitable production until anthropogenic or natural processes result in large scale mortality of the Prosopis overstory.

Introduction

Honey mesquite (Prosopis glandulosa; hereafter: Prosopis) is native to the Southern Great Plains (SGP), USA, but persisted in low densities prior to European settlement due to suppression by fire and competition from grasses (Van Auken 2000). Prosopis expansion throughout the SGP occurred through the exclusion of fire, overgrazing of grasses, and enhanced seed germination via cattle and wildlife endozoochory (Archer 1989, Ansley et al., 2017). Once Prosopis stand-level canopy cover exceeds 30%, C \textsubscript{3} mid-grass production severely declines (Ansley et al., 2004).

Texas wintergrass (Nassella leucotricha; hereafter: Nassella), a native C \textsubscript{3} perennial mid-grass, was thought to occur in small quantities in the C \textsubscript{4}-dominated grasslands characteristic of the region (Stubbendieck et al., 2017) but increased as Prosopis proliferated. Nassella responds more favourably to enhanced CO levels and soil N than C \textsubscript{4} plants providing a competitive advantage under the canopies of leguminous trees today. It initially establishes under Prosopis canopies, then spreads to interspaces as Prosopis density increases (Simmons et al., 2008). It persists under woody canopies by maximizing photosynthesis and growth in early spring while Prosopis is leafless, and then enters dormancy during the summer when Prosopis is in full foliage (Teague et al., 2014). Therefore, it avoids competition with Prosopis for soil resources or light. In interspaces,
C₄ mid-grasses have greater access to light but must compete with Prosopis lateral roots for soil moisture. There, N-fixation by the leguminous shrub may also favour C₄ plants (Ansley et al., 2014). C₃ short-grass roots primarily occupy soil layers above where most Prosopis lateral roots reside. In dense stands of Prosopis, Nassella dominates the woody subcanopy and mixes with C₄-grasses in the interspaces between trees.

We know very little about the stability of the Prosopis/Nassella association or the interactions of C₃ and C₄ grass species following Prosopis disturbance. Neither do we know much about Nassella responses to direct treatments designed to reduce its competitiveness with C₄ grass species. Disturbance-based state-and-transition models indicate that the Prosopis/Nassella-dominated state is reversible to a C₄-dominated community after Prosopis elimination. Earlier studies supported this, but in some cases, possibly due to changes in C₄ grass propagule availability, increased Prosopis density, increased Prosopis and Nassella seedbanks, increased soil N availability, changes in depth of soil moisture penetration or seasonality of soil moisture availability, higher CO₂ levels, or a combination of these factors, the Prosopis/Nassella state seems more resilient and shifts to C₄-dominated communities are more ephemeral when they occur. Such a phenomenon indicates that the Prosopis/Nassella association may now be a stable ecological state that is not reversible without significant changes in the processes and feedbacks driving the system. This paper provides information from a series of studies that, together, provide a systems-level examination of the biogeochemical relationships that determine the resilience of this state and may provide guidelines to manage these processes to facilitate transition to a more desirable community over time.

Materials and Methods
We examined the stability of the Prosopis/Nassella association in a series of three experiments in the SGP. Studies were conducted in north Texas, USA (34°01′52″N; 99°15′00″E; elevation 372 m). Mean annual precipitation is 710 mm and mean annual air temperature is 17.1°C. Soils are 1 to 2-m deep clay loams. The overstory is dominated by Prosopis. The herbaceous layer is comprised primarily of Nassella and the C₃ perennial short-grass, buffalograss (Buchloe dactyloides). C₃ perennial mid-grass species include sideoats grama (Bouteloua curtipendula), vine mesquite (Hopia obtusa), sand dropseed (Sporobolus cryptandrus), and Arizona cottontop (Digitaria californica).

The first experiment quantified perennial grass responses to a mechanical Prosopis top-killing treatment. Treatments, data collection procedures, and statistical analyses are outlined in Ansley et al., (2019). Briefly, grass production and basal cover were measured in top-killed and untreated Prosopis plots from 2007 – 2015. Since herbaceous species dynamics are related to Prosopis canopies, C₃ and C₄ grass responses were measured in intercanopy and subcanopy microsites.

The second experiment quantified grass and forb functional group productivity and soil N responses in subcanopy and intercanopy microsites for 2 years (2015 – 2016) after a root-killing aerial treatment with clompyralid-based herbicides (Ansley et al., in review). Four treated plots were paired with four adjacent untreated areas in a block design. Herbaceous clippings were collected in early summer (late May or June) and fall (late September or October), by functional group: C₃ mid-grasses, C₃ annual grasses, C₃ short-grasses, C₄ mid-grasses, perennial forbs, annual forbs, and litter. At those same times, subcanopy and intercanopy soil samples were collected at 0-15 and 15-30 cm depths for soil inorganic N and water-extractable organic N analyses via the Haney Soil Test procedure (Haney et al., 2010). A split block linear mixed-model was used to test effects of year, treatment, microsite, and their interactions on functional group production and soil N.

The third experiment examined Nassella responses to targeted grazing during peak cool-season growth (Hood 2019). Treatments included 1) ungrazed control, 2) one grazing period during February 2018, and 3) two grazing periods (February and late March 2018). All plots contained live, untreated Prosopis. Grazed treatments were stocked with cattle to approximately 33,600 kg live weight ha⁻¹ for 12 – 20 h to achieve a 5-cm grass stubble height in treated plots. We assessed herbaceous species coverage in January 2018 prior to treatment initiation, during Nassella reproduction (May) and dormancy (September), and again during the Nassella growing season (January 2019). In May 2018, Nassella reproductive tillers were separated from vegetative material to determine grazing effects on reproductive tiller density. For additional details about treatments, data collection procedures, and statistical analyses see Hood (2019).
Results

**Herbaceous Responses following Mechanical Top-kill of Prosopis**

Nassella production was 2 – 3 times greater in the top-kill than untreated intercanopy for three years after treatment (Ansley et al., 2019). Intercanopy C₄ mid-grass production increased in year 4 but severe drought stopped recovery in years 5 – 7. Recovery resumed in year 8, but by that time Prosopis regrowth was large enough to limit C₄ mid-grass production to a third of its potential. Nassella basal cover dominance remained stable in untreated subcanopy microsites, even during drought. Following a brief decline in the untreated subcanopy microsites, Nassella cover returned to pretreatment levels by year 8 as Prosopis regrowth increased to pretreatment levels. The Prosopis/Nassella association thus limited the window of C₄ mid-grass recovery to only a few years following Prosopis top-kill suppression.

**Herbaceous and Soil Responses following Chemical Root-kill of Prosopis**

Perennial grass production and total herbaceous production were greater in treated than untreated subcanopy and intercanopy microsites 1-yr after Prosopis root-kill, due to increased Nassella production. Nassella and C₄ perennial grass production declined in treated microsites at 2-yrs post-treatment mainly because a spike in annual forb production replaced grass production. As a result, total herbaceous production remained greater in treated microsites than untreated microsites. Similar to the top-kill study, Prosopis treatment had no effect on C₃ short- or mid-grass production within the first few years post-treatment. Soil inorganic N increased from year 1 to year 2 in treated intercanopy and untreated and treated subcanopy. Correspondence analysis showed forb production was strongly linked to treated subcanopy, with weaker links to soil inorganic N and treated intercanopy in year 2.

**Nassella Responses to Targeted Grazing**

Ungrazed Nassella cover was stable across all four measurement periods. In grazed-once and grazed-twice plots, Nassella cover was greatest in January 2018, prior to grazing initiation. By January 2019, Nassella cover decreased 65 and 62% in grazed-once and grazed-twice plots, respectively. From January 2018 to January 2019, bare ground increased 122 and 391% in the grazed-once and grazed-twice plots, respectively. Nassella in grazed-twice plots produced fewer reproductive tillers than the other treatments.

Discussion and Conclusions

Woody species facilitation of C₃ grass expansion in C₄-dominated grasslands similar to the Prosopis/Nassella association discussed here, has been documented in other parts of Texas, the USA, and worldwide. Huísache (Acacia farnesiana) and Ashe juniper (Juniperus ashei) were associated with increased Nassella production in south and central Texas, respectively (Scifres et al., 1982, Fuhlendorf et al., 1997). In semi-arid rangelands of Argentina, Peruvian feathergrass (Stipa ichu) and Mexican feathergrass (Nassella tenuissima) were associated with Prosopis species in C₃/C₄ mixed grasslands where C₃ grasses had previously been dominant (Rossi and Villagro 2003, Rauber et al., 2014). South African grass communities under sweet thorn (Vachellia karroo) became dominated by C₃ narrow-leaved turpentine grass (Cymbopogon plurinodis) to the exclusion of C₄ red grass (Themeda triandra) (Stuart-Hill and Tainton 1989). In Australia, Prober et al., (2005) reported that woodland understories became dominated with exotic C₃ annual grasses and the native C₃ perennial grass, snow tussock (Poa sieberiana).

Our first study demonstrated that a single top-kill event had little impact on the Prosopis/Nassella association to allow C₃ mid-grass recovery (Ansley et al., 2019). C₃ mid-grass production did not begin to replace Nassella until year 3 of the first study, and drought disrupted that trend. The second study suggests that root-killing Prosopis treatments need more than two years post-treatment for C₃ mid-grasses to respond. The combination of high rainfall in the fall of year 1, increased light to the soil surface following Prosopis root-kill, and increased soil inorganic N culminated in unexpected increased annual forb production in year 2. Results indicate that the Prosopis/Nassella association may even be resilient to root killing treatments if a flush of soil nitrogen and/or depleted seedbanks coincide with unusually wet seasonal rainfall immediately following treatment. The third study suggested that targeted grazing could be used to reduce Nassella dominance, but bare ground, rather than C₃ species, replaced Nassella in the single year of treatment.

Collectively, the three studies verify that pre-treatment spatial heterogeneity of herbaceous composition and soil N, caused by Prosopis, affect post-treatment herbaceous community dynamics and production. Study 2 revealed that even if there is an increase in Nassella production initially after treatment, under certain conditions the potential remains for forb production to replace C₃ grass production in subsequent years, although our
study measured responses at only 1 and 2 years post-treatment. The longer-term study (study 1) found no difference in forb production between treated and untreated Prosopis sites during 9 post-treatment yrs. Prosopis suppression (i.e., top-kill) treatments that stimulate woody regrowth do not appear to be an effective means of reducing Nassella and restoring C₄ mid-grass dominance. Longer-term studies are needed to assess the merits of root-killing Prosopis treatments on this transition along with additional years of research on targeted grazing of Nassella following Prosopis root-killing treatments. Other management actions, such as augmenting the C₄ mid-grass seedbank and/or utilization of grass-specific, selective herbicides may be needed to suppress Nassella production and enhance C₄ recruitment if the removal of Prosopis alone is not sufficient. The return to a C₄-dominated community will be a long-term process, and persistent management that particularly favors C₄ mid-grasses or costly inputs will be needed to change the biological and ecological feedbacks that favored the Prosopis/ Nassella state. Without putting the proper processes in place (e.g., seedbanks, improved C₄ reproduction and germination) to enable the response of C₄ grasses to Prosopis mortality, Prosopis root-kill alone may not guarantee a sustained shift back to C₄ grassland.

Acknowledgements
We appreciate the field data collection provided by Kim Peters, Mustafa Mirik, Brady Surber, Carlen Smith, and Kristy Melton. Dr. Bill Pinchak and Justin Miller coordinated cattle movement to research plots in the targeted grazing study. The USDA-ARS Blackland Research Center assisted with soil analyses. Research was funded by DOE SECO Bioenergy Grant 403, Dow AgroSciences (now Corteva), the USFWS Wildlife Restoration Program through the Texas Parks and Wildlife Department, USDA Hatch Funding, Texas A&M AgriLife Research, and Texas A&M AgriLife Extension.

References


Hood, K.E. 2019. Combating a native invasion: Targeted, growing season defoliation effects on Texas wintergrass (Nassella leucotricha) canopy cover, seed production, and regrowth under honey mesquite (Prosopis glandulosa) canopies in north central Texas. MS Thesis. Stephenville, TX: Tarleton State University.


Characterization of degree of Eco-restoration by tree-grass interaction in degraded lands of Semi-arid Tropics


1ICAR-Indian Grassland and Fodder Research Institute, Jhansi 284 003, India; 2ICAR-Indian Grassland and Fodder Research Institute, Jhansi 284 003, India

Key words: Land degradation; Carbon sequestration; Carbon management index; Biological activity index

Abstract
Land degradation majorly declines soil health. Eco-restoration through tree-grass interaction provides a perfect solution to restore degraded lands. The study was carried out at Jhansi district of India from 2010 to 2019 with three fodder trees viz; namely, Ficus infectoria, Morus alba, and Acacia nilotica and a shrub Leucaena leucocephala (along with three types of grass (Cenchrus ciliaris, Chrysopogon fulvus and Panicum maximum). The main objectives of these study were to a) assess the changes in soil organic carbon pools and responses of soil enzymes as impacted by different eco-restoration strategies involving trees and grasses; and b) develop an index to measure the efficiency of eco-restoration strategies to aid the community. Grass and tree biomass yield was highest for Panicum maximum and Ficus infectoria, respectively. After nine years, land under Ficus, Morus, and Acacia had ~ 63, 105, and 87% greater total organic carbon. Cenchrus, Panicum, and Chrysopogon increased total organic carbon 84, 91, and 77% at surface layers, respectively, over fallow land. Microbial biomass C increased by 2-2.5 folds in both soil layers. There was a positive correlation between all the C fractions and eco-restoration efficiency. Carbon management index (CMI) enhanced by 51, 84, and 70% at surface layers under Ficus, Morus, and Acacia based systems, respectively, over fallow land. Similarly, grasses also improved CMI by >60%. Accumulation of soil organic carbon under Ficus, Morus, and Acacia were ~55, 91, and 77% higher than fallow land at surface layers. We developed an eco-restoration efficiency index by combining the CMI and biological activity index. We found Morus + Panicum, Acaia + Panicum to be effective restoration strategies for eco-restoration under degraded lands of tropical climates. Our study indicated that implementing these eco-restoration strategies could be a quantitatively important component of climate change mitigation strategies in India and should be continually paid great attention.

Introduction
Land degradation has been one of the major causes of diminishing soil quality in recent years. Restoration of degraded lands has been challenging. It involves careful planning and adopting land use options. Land use options promoting sustainability and livelihood security are desirable by society for enhancing food, fodder and firewood, mitigation and adaptation to climate change (Kumar et al., 2019).

There have been many studies on the response of land restoration strategies to SOC storage in temperate climates. However, the knowledge on the response of land restoration strategies to SOC storage in tropical climates, C distribution in different pools, soil enzyme activities has remained scanty. The most discriminant factors among eco-restored land are also unknown under tropical climate. There is no available index to measure the efficiency of eco-restoration strategies. Systematic information on the capability of these strategies to fulfil the commitment of the Paris Agreement is also unavailable. The main objectives of the study were to a) assess the changes in soil organic carbon pools as affected different eco-restoration strategies involving trees and grasses; b) find out the response of soil enzymes due to eco-restoration of degraded land in the tropical climate, and c) develop an index to measure the efficiency of eco-restoration strategies to aid the community.

Materials and Methods

Study Site
The study site is located at Jhansi, India (longitude 250 26’08” N, latitude 780 30’21” E and altitude 216 m above mean sea level). Geologically, the
area belongs to the part of the Bundelkhand region, which is characterised by a devastating drought, barren soil and extreme climate. Rocks like gneisses and granites with highly ferruginous beds and basic igneous intrusions are observed in this tract. The soil of the experimental site belongs to the hypothermic family of Typic Haplustepts with clay loam texture. Three native fast-growing fodder trees: Ficus infectoria, Morus alba, Acacia nilotica and a shrub, i.e. Leucaena leucocephala (occurring naturally in most arid and semiarid regions), were selected for fodder supply from March to June. A combination of three grass species viz., Cenchrus ciliaris, Chrysopogon fulvus and Panicum maximum were tried along with tree components to test their compatibility for higher biomass and quality during August to February. In April 2019, soil samples were collected in four replicates from each eco-restored land at two depth layers (0–15 and 15–30 cm). After HCl treatment, total organic C (TOC) was measured following the dry combustion method with a CHN analyser. The carbon management index (CMI) was calculated using the following equations (Blair et al., 1995) using fallow land as reference. A biological activity index (BAI) was computed (Ghosh et al., 2021). Eco-restoration efficiency of each system (ERE) was calculated as

\[
ERE = \frac{BAI \times CMI}{100}
\]

**Results**

**TOC**

Land under Ficus, Morus, Acacia and Leucaena had ~63, 105, 87 and 81% greater TOC than fallow land in the surface layer and 78, 97, 109 and 77% greater TOC than fallow land in the subsurface layer, respectively (Table 1). Cenchrus, Panicum, and Chrysopogon increased TOC among the grasses by a) 84, 91 and 77% at 0-15 and b) 101, 91 and 79% at 15-30 cm soil layers, respectively, over fallow land.

**CMI and BAI**

Eco-restoration strategies significantly improved CMI. After nine years of restoration, Ficus, Morus, Acacia and Leucaena boosted CMI by a) 51, 84, 71 and 65% b) 61, 75, 84 and 59% at surface and subsurface layers, respectively over fallow land (Table 1). Similarly, Cenchrus, Panicum, and Chrysopogon resulted in a) 68, 73 and 62% and b) 78, 70 and 61% improvement in CMI at surface and subsurface soil layers. Hence, although grasses improved CMI over fallow land, their impacts were similar at surface layers. However, CMI was higher in subsurface soils than surface soils under Ficus, Acacia, and Cenchrus. BAI describes the overall improvement in nutrient cycling in the ecosystems as it encompasses the activities of C, N and P cycling enzymes. However, BAI under Ficus, Morus, Acacia and Leucaena were ~a) 3.6, 6.2, 3.7 and 4.5 times and b) 3.8, 4.6, 8.8 and 4 times greater than fallow land at the surface and subsurface soil layers, respectively (Table 1). Although impacts of grass species were similar for individual enzyme activities at surface layers, BAI of land under Cenchrus and Chrysopogon were ~11 and 10% higher than Panicum at the surface layer, respectively. However, Panicum improved BAI by ~31 and 73% over Cenchrus and Chrysopogon, respectively, at the subsurface layer.

**Table 1**: Total soil organic carbon (TOC), carbon management index (CMI), biological activity index (BAI) and eco-restoration efficiency (ERE) in surface (0-15 cm) and subsurface (15-30 cm) soil layers as influenced by 9 years of eco-restoration strategies in a tropical Inceptisol

<table>
<thead>
<tr>
<th></th>
<th>0-15 cm</th>
<th></th>
<th>15-30 cm</th>
<th></th>
<th>0-15 cm</th>
<th></th>
<th>15-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOC (g kg(^{-1}))</td>
<td>CMI</td>
<td>BAI</td>
<td>ERE</td>
<td>TOC (g kg(^{-1}))</td>
<td>CMI</td>
<td>BAI</td>
</tr>
<tr>
<td>Ficus</td>
<td>7.33c</td>
<td>150.7c</td>
<td>3.59c</td>
<td>5.47d</td>
<td>6.6c</td>
<td>160.5c</td>
<td>3.81c</td>
</tr>
<tr>
<td>Morus</td>
<td>9.21a</td>
<td>184.2a</td>
<td>6.18a</td>
<td>11.53a</td>
<td>7.3b</td>
<td>175.1b</td>
<td>4.64b</td>
</tr>
<tr>
<td>Acacia</td>
<td>8.43b</td>
<td>170.4b</td>
<td>3.66c</td>
<td>6.21c</td>
<td>7.73a</td>
<td>184.2a</td>
<td>8.8a</td>
</tr>
<tr>
<td>Leucaena</td>
<td>8.13b</td>
<td>165b</td>
<td>4.49b</td>
<td>7.71b</td>
<td>6.53c</td>
<td>159.1c</td>
<td>4.04bc</td>
</tr>
<tr>
<td>Fallow</td>
<td>4.5d</td>
<td>100d</td>
<td>1d</td>
<td>1.0d</td>
<td>3.7d</td>
<td>100d</td>
<td>1d</td>
</tr>
<tr>
<td></td>
<td>TOC (g kg(^{-1}))</td>
<td>CMI</td>
<td>BAI</td>
<td>ERE</td>
<td>TOC (g kg(^{-1}))</td>
<td>CMI</td>
<td>BAI</td>
</tr>
<tr>
<td>Cenchrus</td>
<td>8.3b</td>
<td>168a</td>
<td>4.68a</td>
<td>8a</td>
<td>7.45a</td>
<td>178.2a</td>
<td>5.21b</td>
</tr>
<tr>
<td>Panicum</td>
<td>8.58a</td>
<td>172.9a</td>
<td>4.21c</td>
<td>7.34c</td>
<td>7.05b</td>
<td>169.9ab</td>
<td>6.82a</td>
</tr>
<tr>
<td>Chrysopogon</td>
<td>7.96c</td>
<td>161.8a</td>
<td>4.55b</td>
<td>7.85b</td>
<td>6.63c</td>
<td>161b</td>
<td>3.93c</td>
</tr>
<tr>
<td>Fallow</td>
<td>4.5d</td>
<td>100b</td>
<td>1d</td>
<td>1.0d</td>
<td>3.7d</td>
<td>100c</td>
<td>1d</td>
</tr>
</tbody>
</table>
Discussion[Conclusions/Implications]

Based on ERE values, we found that *Morus* and *Acacia* were the most efficient trees for restoration of degraded land and *Panicum* was the most efficient grass for restoration of degraded land under the tropical climate of *Bundelkhand* region of India, and their eco-restoration efficiency was ~10 times greater than fallow land (Table 1).

ence, *Morus + Panicum, Acacia + Panicum* could be effective restoration strategies for eco-restoration under degraded lands of tropical climates. Despite clearly indicating an effective system for eco-restoration, we plan to test the index under diverse soil orders eco-restoration strategies to improve the positive correlations observed here. We also plan to develop baseline data set for diverse soil types and climate for its rapid application and uses so that this easy, quick, effective index can be made operational for calculating the efficiency of eco-restoration strategies at ease for urgent implementation of effective strategies to meet the commitment of Paris agreement.

**Acknowledgements**

The authors are sincerely thankful to Director, ICAR-IGFRI, Jhansi, India for his kind support and encouragement during the study.

**References**


Counteracting green alder shrub expansion by low-input grazing

Schneider M.K.1; Zehnder T.1,2; Berard J.2,3; Pauler C.1; Staudinger M.1,2; Kreuzer M.2 and Lüscher A.1

1 Agroscope, Forage Production and Grassland Systems, Zurich, Switzerland
2 ETH Zurich, Institute of Agricultural Sciences, Zurich, Switzerland
3 Agroscope, Animal Production Systems and Animal Health, Posieux, Switzerland

Key words: abandonment; biodiversity; grazing; robust breeds; green alder

Abstract
In the past decades, the decline of traditional agriculture has caused an abandonment of marginal pastures in many mountain areas of Europe. In the Swiss Alps, green alder (Alnus viridis) is the most abundant successional shrub. A survey of 24 pasture-shrub gradients showed that the encroachment by green alder, in contrast to other shrubs, is associated with a substantial decline in plant species richness. The understorey of alder is primarily populated by very few, broad-leaved herbaceous species benefitting from the atmospheric nitrogen fixed by actinomycetes in symbiosis with green alder. However, the understorey vegetation also provides an underestimated forage, rich in protein and comparable in productivity and digestibility to nearby open pastures. A two-year grazing experiment with cattle (Dexter), sheep (local Engadine sheep) and mixed-breed goats in the Eastern Swiss Alps demonstrated that robust breeds were able to exploit these resources as they readily penetrated the thickets. The Engadine sheep and the goats consumed green alder bark and thus actively counteracted shrub encroachment. Dexter cattle did not forage on alder bark but on leaves and opened the thickets by their movement through them. Since goats preferred other woody species to green alder and depleted them before the alder, they may impair the regeneration of late-successional forest. Dexter heifers and Engadine lambs performed equally well on pastures with high shrub cover and on open pastures in terms of average daily weight gain, carcass and meat quality. This was facilitated by the comparatively low productivity of these breeds. In this way, low-input grazing systems utilizing adapted breeds, especially sheep, can add to conservation goals and sustain a viable meat production in marginal areas.

Introduction
Farming in European mountain regions has considerably changed during recent decades. Emigration and increased employment outside the agricultural sector have strongly decreased labour availability. Consequently, land use was intensified on fertile land accessible by machinery, while low-productive and remote areas were increasingly abandoned (Strebel and Bühler 2013). In addition, there were shifts in livestock systems from intensive milk to extensive meat production, for example from dairy cows to suckler beef cattle or from dairy goats to sheep lambs (Herzog and Seidl 2018). Reduction of farming activities has led to an increase in reforestation and shrub encroachment, primarily in abandoned pastures. In the Swiss Alps, the shrubland area increased by 18% between 1995 and 2017 (Brändli et al., 2020). In the Alps, 70% of all shrublands are dominated by green alder (Alnus viridis (Chaix) DC.), a pioneer species which takes advantage of atmospheric nitrogen fixed by the symbiotic actinomycete Frankia alnii. The fixed nitrogen is eventually released into nutrient-poor ecosystems, eutrophicating surrounding soils and streams (Bühlmann et al., 2016). Due to the high nitrogen availability, the understorey vegetation of green alder is dominated by a few broad-leaved herbs such as Adenostyles alliariae L. and Peucedanum ostruthium L. (Zehnder et al., 2020). Hence, the encroachment with green alder threatens the rich biodiversity and the aesthetic value of mountain pastures. Moreover, the shrub impedes animal movement and the utilisation of the remaining open areas. We therefore aimed to develop and test strategies to stop or even reverse alder encroachment on species-rich mountain pastures while maintaining a viable meat production.

Materials and Methods
A grazing experiment was set up using Dexter cattle, Engadine sheep and mixed-breed goats
on two neighbouring areas on both sides of the Albula pass (Canton of Grisons, Switzerland, 46° 34’ N, 9° 50’ E) at an elevation of 1900-2200 m a.s.l. All chosen breeds were of low productivity and adapted to roam steep terrain and to feed on low-quality forage. Dexter cattle (heifers of 1-2 years) and local Engadine sheep (ewes and their lambs) were evenly split into four groups each. The groups were assigned to pastures with different degrees of shrub encroachment ranging from 0% to 80% cover of green alder. In addition, a group of mixed-breed goats grazed paddocks with the highest alder cover. Each group grazed three different paddocks with similar shrub cover twice. To assess the interaction of grazing animals and the pasture, we measured various parameters: (1) Forage biomass was sampled from grazing exclusion cages (1.2 × 1.2 m) placed in different vegetation types classified according to Dietl et al., (2002). Digestibility of organic matter was analysed in vitro according to Tilley and Terry (1963). (2) Movement of selected animals was monitored by GPS trackers at a frequency of 10s using the methodology of Homburger et al., (2015). (3) After each rotation, areas encroached by green alder were systematically searched for signs of bark removal. The proportion of damaged branches was quantified and their location recorded. (4) Before the experiment and after each rotation the animals were weighed to quantify daily gains in body weight. (5) After grazing the experimental pastures for eight weeks, the animals were slaughtered and their carcass and meat quality was assessed. Significance of differences was tested by pairwise comparison with Tukey contrasts.

Results and discussion

Green alder stands are an underestimated forage resource

Because of the high elevation, annual biomass yield was low, but differed significantly among vegetation types (Table 1). The highest mean yields of 2.3 t/ha were measured in fertile pastures and nitrophilous areas, and these were higher (P<0.05) than the average of 0.9 t/ha in the nutrient-poor pastures. The understorey vegetation of green alder produced 1.5 t/ha on average. In addition, measurements by Wiedmer and Senn-Irlet (2006) indicated an annual production of around 3.8 t of alder leaves and 1 t/ha of bark. There was no significant difference in in vitro digestibility between the understorey vegetation of green alder and the vegetation of open pastures. The digestibility of alder leaves was slightly lower (P<0.05) than for nutrient-poor pastures and understorey vegetation. The bark, however, was substantially less (P<0.05) digestible than herbs and alder leaves. The crude protein content was higher (P<0.05) in the understorey vegetation of green alder and in alder leaves than in the other vegetation types and in the bark. This is explained by the additional input of symbiotically fixed nitrogen provided by green alder (Bühlmann et al., 2016). Commonly, green alder and its associated vegetation are assumed to be of low forage quality. However, the high digestibility and protein content combined with the relatively high productivity of the understorey show that this vegetation type provides an underestimated forage resource for adapted low-productive ruminants.

Table 1: Annual biomass yield, in vitro digestibility of organic matter and crude protein content in the dry matter of different vegetation types and plant parts of green alder (Alnus viridis). Shown are mean values ± one standard deviation. Different letters indicate significant differences of pairwise comparison with Tukey contrasts at 5% level

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Annual yield (t/ha)</th>
<th>Digestibility (g/kg DM)</th>
<th>Crude protein (g/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertile and nitrophilous pastures</td>
<td>2.25 ± 0.89 b</td>
<td>487 ± 114 bc</td>
<td>117 ± 37 a</td>
</tr>
<tr>
<td>Nutrient-poor pastures and wetlands</td>
<td>0.93 ± 0.52 a</td>
<td>531 ± 60 c</td>
<td>133 ± 34 a</td>
</tr>
<tr>
<td>Green alder understorey vegetation</td>
<td>1.53 ± 0.89 ab</td>
<td>559 ± 75 c</td>
<td>190 ± 39 b</td>
</tr>
<tr>
<td>Green alder leaves</td>
<td>3.8 *</td>
<td>439 ± 54 b</td>
<td>211 ± 21 b</td>
</tr>
<tr>
<td>Green alder bark</td>
<td>1.04 *</td>
<td>163 ± 12 a</td>
<td>78.1 ± 8.8 a</td>
</tr>
</tbody>
</table>

* Estimates measured and published in Wiedmer and Senn-Irlet (2006)
**Ruminant species differ in feeding behaviour**

All three ruminant species exploited the areas encroached by green alder. Dexter cattle were not hindered in movement by the shrubs but they showed a clear preference for open pastures (Figure 1a). They were observed foraging on understorey vegetation as well as browsing alder leaves and buds. In contrast, Engadine sheep only slightly preferred open pastures to areas encroached by alder (Figure 1b) and frequently foraged some of the plants abundantly available in the alder understorey. In addition to leaves and buds, Engadine sheep also stripped the bark at the basis of green alder branches and consumed it, especially at the edge of the stand, where the sheep could access the shrubs more easily than in the centre. This resulted in partial damage to many alder plants, since debarked branches lose their transport capacity for assimilates and thus, die back. The goats showed almost no preference for open pastures over closed stands of green alder (Figure 1c). They consumed alder leaves and buds but very rarely alder bark. In contrast, the bark of the few elderberry trees (*Sorbus aucuparia* L.) growing in the alder stands was almost completely stripped. Goats consumed the bark of elderberry immediately when released to the paddocks, whereas they debarked green alder only when very little elderberry was left over.

**Figure 1:** Foraging density (i.e. the relative number of GPS locations classified as foraging per grid cell) and proportion of debarked branches in exemplarily selected paddocks grazed by Dexter cattle (a), Engadine sheep (b) and mixed-breed goats (c). Hatched polygons are areas covered by green alder (*Alnus viridis*). Dots show debarked plants of green alder or elderberry (*Sorbus aucuparia*) as well as unabarked plants. Dot size is scaled by the proportion of branches with removed bark.

**Grazing of green alder areas did not impair animal performance**

The cover of green alder on pastures did not affect the average daily weight gain of the Dexter heifers and Engadine lambs (Table 2). Weight gain was positive in all groups and there were no significant differences attributable to shrub cover. For Dexter cattle, the lowest weight gains were observed in the group grazing pastures with a cover of green alder of around 80%. In contrast, the weight gain of Engadine lambs increased with the areal share covered by green alder. This may be due to a higher preference of this sheep breed for alder leaves and understorey vegetation. Likewise, the dressing percentage of the animals (i.e., proportion of carcass after removal of blood, visceas, skin, head and feet to live weight) did not decrease with increasing cover of green alder (Zehnder *et al.*, 2016). Engadine sheep even had a higher dressing percentage in pastures with medium and high covers of green alder than on open grassland. Pasture type did also not have an influence on the shear force of the meat, a measure of tenderness (Zehnder *et al.*, 2016). Hence, the substantial biomass available in the alder stands and the high digestibility and protein content of the understorey vegetation and of the alder leaves (Table 1) provided an adequate nutrient supply for the investigated robust livestock breeds.
Table 2: Average daily weight gain (g/d) ± standard error of Dexter cattle and Engadine lambs grazing areas with different degrees of green alder cover. No significant differences at P<0.05 were found

<table>
<thead>
<tr>
<th>Cover of green alder</th>
<th>Dexter cattle</th>
<th>Engadine lambs</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (0%)</td>
<td>186 ± 42 a</td>
<td>104 ± 14 a</td>
</tr>
<tr>
<td>Low (20%)</td>
<td>242 ± 42 a</td>
<td>92 ± 12 a</td>
</tr>
<tr>
<td>Medium (60%)</td>
<td>201 ± 40 a</td>
<td>132 ± 15 a</td>
</tr>
<tr>
<td>High (80%)</td>
<td>127 ± 39 a</td>
<td>131 ± 15 a</td>
</tr>
</tbody>
</table>

Conclusions and implications
The forage provided by green alder stands is generally underrated in the nutrition of adapted low-productive ruminants. The present study demonstrated that the abundant understorey vegetation as well as alder leaves have relatively high yields with high estimated digestibility and crude protein content. Consequently, all investigated breeds of different ruminant species exploited green alder stands, as revealed by GPS tracking. However, the breeds differed in their preference of understorey vegetation and alder parts. This has important implications for practical use: Dexter cattle have the smallest direct impact on alder, but they exploit the understorey vegetation and can open up green alder areas for other types of animals. Engadine sheep actively counteract alder expansion by consuming its bark. Hence, they provide an attractive option for regaining open pastures, but they mainly stay within the edge of dense alder stands. Since goats prefer other woody species to green alder and deplete them first, they must be kept under high grazing pressure to drive back alder shrubs. Otherwise, they may only hinder the regeneration of late-successional forest. Finally, the study demonstrated that growth performance, carcass and meat quality are not impaired in animals grazing green alder pastures.

In contrast to previous assumptions by practitioners and scientists, green alder stands are a forage resource in marginal mountain areas, at least when exploited by low-productive breeds. Therefore, using green alder and its understorey as forage for robust livestock breeds has a double positive effect: The grazing animals sustainably produce organic meat on areas otherwise abandoned and, in this way, maintain or restore valuable species-rich grassland.

Acknowledgements
This research was funded by the Mercator Foundation Switzerland Program of the World Food System Center at ETH Zurich.

References


Rangeland management in a changing world – active and passive restoration case studies from Ethiopia, Tanzania, and South Africa

Treydte, A.C.1; Baumgartner, S.A.2; Tuffa, S.K.3; Abdeta, A. A.4

1School of Life Sciences and Bioengineering, Nelson Mandela African Institution of Science Technology, Arusha, Tanzania and
2University of Hohenheim, Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute) and
3Oromia Agricultural Research Centre, Ethiopia
4Faculty of Natural Resources, Botswana University of Agriculture, Gaborone, Botswana

Key words: exclosures; woody and herbaceous vegetation; livestock species diversification; savannas; soil and grass nutrients

Abstract

Rangelands cover almost 50% of the earth’s land surface and are often found in marginal areas that often face climate extremes. The production of herbaceous biomass has strongly declined over the last decades due to overgrazing and adverse climatic conditions such as frequent droughts and flooding. While different rangeland restoration methods are being used, their effect on vegetation quality and quantity over time has rarely been experimentally tested and monitored. Our research comprises experiments of various rangeland restoration tools we have used across eastern and southern Africa. We conducted passive restoration through exclosure experiments and compared vegetation in and outside of exclosures to understand regrowth patterns as well as overall forage quality. The active restoration methods we tested comprised domestic livestock species diversification, that is, inclusion of browsers in rangeland systems. Further, we investigated how reseeding of nutritious rangeland grass species and subsequent grazing regimes can improve the rangeland health. We found that exclosures strongly improved biomass and productivity but that regular moderate grazing can further enhance those compared to no grazing. Our results further suggest that including browsers might enhance nutrients of herbaceous vegetation and soils of rangeland systems. We also claim that young grass species such as Chloris gayana and Cenchrus ciliaris, which are commonly used for reseeding of rangelands, show higher nutrient contents and productivity under light or moderate grazing pressure while mature grasses did not show this effect. We conclude that a combination of active and passive restoration methods can greatly enhance quality and quantity of African rangelands and enhance their sustainable use and resilience towards climatic shocks such as increasing drought frequencies.

Introduction

Rangelands cover almost 50% of the earth’s land surface and are often found in marginal areas, unsuitable for cropping. The production of herbaceous biomass and woody vegetation is highly seasonal and climate-dependent. Rangelands support over 2.5 billion people (UN 2008) and the global demand for livestock products is increasing (Bouwman 1997). Currently, 96% of the mammal biomass on the earth is composed of humans and livestock alone (Yinon et al., 2018). Recently, the number of domestic herbivores has rapidly increased to fill this demand. The United Nations has announced the Decade on Ecosystem Restoration (2021-2030), highlighting the importance of understanding restoration interventions in African rangelands (UN 2019). Various rangeland restoration methods have been suggested but little has been quantified about their effect on vegetation and soil recovery. One passive restoration method used globally has been exclosures that either fully or selectively exclude livestock herbivory (e.g., Rong et al., 2014). However, herbaceous biomass as well as productivity and nutrient contents in plants and soil have rarely been quantified and compared between grazing regimes. In addition, little is known on the long-term effects of exclosures on grass biomass and how the rainfall regime impacts grass regrowth.
An active restoration model is to diversify the herbivore species, i.e., including browsers and grazers into a rangeland system rather than a mono-specific herd. It has been shown that livestock, particularly cattle in high numbers, can severely damage the grass layer and soil properties. Few studies have addressed whether different livestock species assemblages will have different effects on both woody and grassy vegetation and whether the inclusion of browsers is beneficial to overall rangeland quality.

Another active method for restoration has been reseeding, which has generally shown positive effects on rangelands and their inhabitants (Davy et al., 2017). Despite the widespread use, few studies have addressed how young plants respond to grazing after their seeding and establishment and what grazing intensity is appropriate for enhancing productivity and nutrient contents for the plants’ sustainably.

We tested various active and passive restoration methods and monitor quantify their success over time for eastern and southern African rangeland systems.

Materials and Methods

Passive restoration. We selected exclosures of different age within the Borana rangeland, Yabello region, of southern Ethiopia. Here, we selected six traditional range enclosures of varying ages (12 to 30 years) and measured the biomass, cover and species richness of the herbaceous vegetation inside and outside the exclosure. We used a linear model to compare herbaceous vegetation characteristics across grazing management and season. We further identified herbaceous species and their grazing value as well as woody vegetation components between inside and outside exclosures.

Active restoration. To assess the importance of livestock species diversification, we selected communal grazing lands of different livestock species composition (cattle only vs cattle, goats and sheep) adjacent to the Kruger National Park, South Africa. At each site, we selected information on grass cover, biomass as well as nutrient contents (Nitrogen and Phosphorus) at systematically distributed sampling points. To address the importance of reseeding in improving rangeland forage quality, we planted Chloris gayana and Cenchrus ciliaris and exposed young and mature tufts to different grazing pressure (clipping) and rainfall regimes (irrigation). We measured regrowth potential as well as Nitrogen content in these grasses.

Results

Passive restoration

Herbaceous biomass, cover and species richness were about 20% higher in exclosures compared to openly accessible communal grazing lands (F = 145, P < 0.001, F = 140, P < 0.001, F = 17.6, P < 0.001). The younger enclosures showed slightly larger differences than the older ones. More desirable grass and forb species were found inside the exclosures than in the outside as well as a lower woody species density.

Active restoration

Our livestock species diversification results showed that grass Nitrogen contents were by about 1/3 higher in sites that included browsers compared to sites with only mono-specific cattle grazing (F_{1,107} = 69.4; P < 0.001). Grass phosphorus contents showed similar but less strong patterns (F_{1,35} = 5.7; P = 0.023). During our reseeding experiment, we found that young grasses of C. ciliaris showed about twice as high biomass under light and moderate grazing than under no or frequent grazing (F_{3,72} = 5.4, p = 0.002). Mature C. ciliaris showed higher below-ground carbon under frequent and moderate grazing compared to no and light grazing (F_{2,61} = 4.6; P = 0.0146). Low irrigation reduced above-ground carbon of both plant species, irrespective of grazing regime (F_{2,61} = 8.5, P = 0.0006; F_{2,61} = 15.0, P < 0.0001).

Discussion

Passive restoration

Our findings that exclosures provide important grass resources for both livestock and wildlife fit well with studies in eastern and southern Africa, where traditional rotating resting of the rangeland has been practiced for centuries (Alemie and Gebremedhin 2019, Venter et al., 2017). We also highlight that older enclosures will likely succumb to self-thinning of grasses, leading to lower productivity in the long run (Enquist et al., 1998). Hence, regular but moderate grazing is recommended to promote productivity and quality of the herbaceous layer in rangelands.

Active restoration

Further, we found that inclusion of browser species can highly improve the nutrient content of the herbaceous layer. This might be due to the higher nutrient contents in browser dung (see also Sitters and Olde Venterink 2018) as well as the lower impact on the herbaceous layer despite similar stocking densities of domestic herbivores (see also Mohammed et al., 2020). However, goats can also severely hamper tree seedling
growth and they might turn to grasses rather than browse if these are nutritious (Ventura-Cordero 2018), which might also have a negative impact on the overall tree-grass balance in the rangeland system. Hence, we recommend enhancing mammalian herbivore species diversification and promoting resting periods and moderate offtake for freshly reseeded grasses in tropical rangeland systems for a sustainable management.

Acknowledgements
We acknowledge the Food Security Centre at the University of Hohenheim, funded through the German Academic Exchange (DAAD), which financed field logistics and research activities. Further, the Foundation Fiat Panis funded parts of this work as well. We thank field assistants and local research centres for support during sampling activities.

References


Rejuvenation of rangelands – role of diversity and improvement strategies of range grasses

Roy, A. K.; Malaviya, D. R.; Kaushal, P.

1ICAR- Indian Grassland and Fodder Research Institute, Jhansi, India
2ICAR- Indian Institute of Sugarcane Research, Lucknow, India
3ICAR- National Institute of Biotic Stress Management, Baronda, Raipur, India

*Corresponding author email: royak333,rediffmail.com ; royak333@gmail.com

Key words: Rangeland; Forage; livestock; Forage Plant Genetic Resources; Perennial grasses

Abstract

In India, a major part of the rural economy depends on grazing-based livestock husbandry, a unique integration of agriculture and livestock coupled with rich traditional knowledge. Hence, ecosystems of common property resources had been a mainstay in rural economy and livelihood. However, the traditional grazing forage resources in arid and semi-arid regions have deteriorated due to various factors, including heavy grazing pressure, climate change, and dominance of invasive species, thus needing rejuvenation. Additionally, these are causing serious economic and ecological problems such as poor productivity, soil and water erosion and reduced carbon sequestration.

The genetic improvement of these grasses encounters various problems such as polyploidy, apomixis, seed shedding and shattering and poor seed to ovule ratio. Transfer of desirable traits from donor germplasm becomes difficult due to the existence of apomixis. The breeding objectives are also multifold, including herbage yield, forage nutritional quality, abiotic stress tolerance etc. Identification of sexual lines is a prerequisite for the transfer of traits. Mutation attempts are also not effective due to polyploidy. ICAR-Indian Grassland and Fodder Research Institute, Jhansi has collected rich genetic diversity in these range grasses, especially Dichanthium-Bothriochloa complex, Heteropogon, Chrysopogon, Sehima, Panicum, Cenchrus, Pennisetum etc. from different parts of the country as well as procurement from gene banks of the world. These germplasms were evaluated for morphological traits that indicated wide variation for various morpho-agronomic traits. The paper deals with reporting the extent of variability among the potential range grasses, with prospects of utilizing the diversity in rejuvenating the degraded rangelands of India and other places with isoclimatic conditions.

Introduction

Grazing-based livestock husbandry is the backbone of India’s rural livelihood and economy and has continued since the dawn of civilization. However, the traditional ecosystem and indigenous knowledge-based grazing management and grassland rejuvenation are now under stress due to various factors like overgrazing, climate change, and anthropogenic interference. As per the recent estimate, there is a shortage of green and dry forage in India (Roy et al., 2019a).

Range grasses and legumes are important components of Indian grasslands. The edible flora for the grazing animals in the rangelands or grassland comprises annual and perennial species. While annuals grow with the onset of the monsoon from the seeds already shed from the previous year’s plants, perennials survive in the form of clumps during the dry season and grow again with the availability of water. Due to heavy grazing pressure, the rangelands are now less productive and unable to provide nutritious fodder to the livestock. The productivity of grasslands can be increased if improved high yielding genotypes with desirable traits such as persistence, stress tolerance, quality and high water use efficiency are seeded in the grasslands.
Genetic improvement of range grasses is challenging for various reasons, such as small flowers, asynchronous flowering, and little understanding of floral biology and pollination mechanism. It is further complicated by the presence of apomixis in most of the tropical perennial range grasses, which hampers the transfer of desirable traits by hybridization. The polyploid nature of these tropical grasses also restricts the use of breeding tools like mutation (Roy et al., 2019b).

The prominent tropical range grasses genera of the Indian rangelands include Bothriochloa, Dichanthium, Cynodon, Panicum, Pennisetum, Cenchrus, Lasiorus, etc. These have good fodder value and have high genetic variability (Roy et al., 2019b). India also has some ethnic grasslands such as Banni Grasslands, Shola grasslands, Sewan grasslands, Terai Grasslands, Kangeyam grassland etc. Many tropical and arid/semi-arid perennial and annual grass species are natural flora of these grasslands. However, these grasslands are under stress due to various factors, and various stages of degradation can be seen.

Several factors have been assigned as reasons for the degradation of these grasslands. Primarily such factors include excessive grazing pressure much beyond the carrying capacity, social factors, policy issues, climate change, the dominance of invasive species, anthropogenic pressure etc. Such degradation leads to serious concerns such as low fodder availability, reducing biodiversity, extinction of characteristic flora and fauna, soil erosion, increased water runoff and poor carbon sequestration. The eco-services rendered by these grasslands are also adversely affected. Hence, a multi-pronged approach is needed for their rejuvenation. However, in this paper, we will be discussing only the role of genetic diversity in preserving and improving Indian grasslands, especially the tropical ones. To limit the scope of this paper, we present here the extent of genetic diversity of the four types of grass, i.e. Sehima nervosum (Sen grass), Dichanthium annulatum (Marvel grass), Heteropogon contortus (Black spear grass) and Megathyrsus maximus (Guinea grass).

**Genetic diversity the source of variation**

Wide diversity for metric traits such as plant height, tiller number/tussock, leaf length, leaf width, number of leaves/tiller etc., exists across the genus in the intraspecies and interspecies level. Similarly, considerable variation in non-metric traits includes habit (such as creeping, erect, prostrate and semi-erect nature), node colour or anthocyanin pigmentation on the node, nodal hairiness, the internodal colour of the culm, leaf colour, leaf blade attitude, flag leaf attitude etc. These non-metric traits contribute to many quality indicators and some traits that make the genotype suitable for specific conditions. Although these grasses are largely apomictic, many forms show facultative apomictic types. Such variation might have been created through the intraspecific, interspecific and intergeneric crossing. It is also possible that more sexual plants occur in natural conditions in this region, allowing recombination in this predominantly apomictic grass.

Several species and races and various intermediate introgressed derivatives of *Dichanthium* and *Bothriochloa* are reported. The presence of wide variability may result from such introgression that got fixed due to apomixis. Earlier studies involving fewer accessions of *D. annulatum* indicated a wide range of diversity independent of their geographical distribution (Agarwal et al., 1999). Similar studies in other tropical perennial grasses also indicated the occurrence of wide variability independent of geographical collection in *Schima nervosum* (Roy et al., 1999); in *Heteropogon contortus* (Roy 2004; Bhat and Roy 2014) and Guinea grass (Jain et al., 2003, 2006, Roy et al., 2020), morphotypes among guinea grass (Malaviya et al. 2006). Diversity among these grasses has been linked with geographical distribution, whereas some other studies indicated the presence of wide diversity independent of geographical origin. The collected germplasm was from several agro-ecological regions of the country, including low hills, arid and semi-arid parts, humid and sub-humid parts, and eastern and western Himalayan zones. Exploiting the variability, several high yielding varieties have been developed in these grasses, which include IGS 9901 (*Sehima nervosum*), Bundel Guinea grass 1, 2, 4, Co-3, PGG-9, PGG-616 (for Guinea grass), Marvel -09-4, JHD 2013-2, Marvel -8 (for *Dichanthium*). Different agencies are popularizing these varieties for enhancing fodder resources in the country. Guinea exhibits diversity for photosynthetic pathways, thus making it suitable for different ecological niches.

**Nutritional Diversity**

*Dichanthium* genotypes exhibit crude protein content variation from 5 to 11% and for IVDMD from 38 to 66%. Among Heteropogon genotypes, CP varied from 2 to 10%, whereas IVDMD varied from 31 to 59%. CP ranged from 3.7 to 7.4% in guinea grass, and the IVDMD ranged from 26 to 50%. In *Sehima nervosum*, these values for CP varied from 2 to 10%, whereas IVDMD varied from 38 to 66%.
52.25. This establishes that enough variability for nutritional parameters is present in nature. Therefore, a suitable selection of genotypes, either in sole culture or in a mixture of genotypes, can improve the total digestible matter output from the grasslands.

**Ways and prospects of diversity utilization for improving grasslands**

This variability can be exploited to get high yielding superior types with desirable traits, which can be introduced in grasslands or pasturelands to get a high yield. The seeds of better high yielding genotypes of these grasses can be seeded in the grasslands in seed pellets or other forms using seed priming techniques to increase germination and establishment. It will lead to higher productivity and better sustenance of such grasslands. Another approach could be putting a mixture of genotypes with distinct morphological traits and identified desirable agronomical or nutritional features, and then leaving such grasslands exposed to varying levels of grazing pressure for long periods with regular observation on the dominance of distinct genotypes in different periods. This allows the natural selection at one hand and identification of genotypes with persistence under variable grazing pressure. On the other hand, the core subset development is a prerequisite for such work because many genotypes can not be taken to field condition; hence representatives of different morphotypes of the core subset can be identified for such an objective. Further, such core development also allows evaluation of such genotypes in target environments for abiotic stresses such as shade, salinity and moisture.

**Acknowledgement**

Authors are thankful to ICAR-IGFRI Jhansi for financial and logistic support.

**References**


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forage Genetics and Improvement
Identification and analysis of flowering time candidate genes of Dactylis glomerata L.

Zhang, X.Q1; Feng, G.Y1; Huang, L.K1; Zhao, X.X2; Yang, Z.F1

1 Department of Grassland Science, Animal Science and Technology College, Sichuan Agricultural University, Chengdu, 611130, China
2 Institute of Urban Agriculture, Chinese Academy of Agricultural Sciences, Chengdu, 610000, China

Key words: Dactylis glomerata L; flowering time; QTL; BSA

Abstract
Orchardgrass (Dactylis glomerata L.) is an important forage grass for cultivating livestock worldwide. Heading date is a surrogate measure of flowering time and is strongly correlated with the yield and quality of forage grasses. Here, we identified 210 flowering-related genes in orchardgrass by BLASTP. In addition, our integrated analysis of transcriptome, quantitative trait locus (QTL), and bulked segregant analysis (BSA) provided insights into the genetic network regulating flowering time. The results revealed that four main candidate genes may participate in flowering time control, including one FT-like gene and three MADS-box genes. Expression investigation between the early-flowering and late-flowering phenotype of orchardgrass indicated gene DG6G02970.1 was the only significantly differentially expressed gene, which encodes the MADS-box gene AGL61-like. Three nonsynonymous SNPs were identified in the AGL61-like gene, resulting in changes from alanine to valine, alanine to threonine and glycine to valine, most likely to cause differentially expression pattern in early-flowering and late-flowering phenotype of orchardgrass. Weighted gene co-expression network analysis (WGCNA) revealed that AGL61-like is associated with a set of 114 genes relevant to carbohydrate metabolic, oxidative stress response and glycolysis/gluconeogenesis process. These results provided useful clues for flowering time regulation in molecular breeding of forage grasses.

Introduction
Flowering is a crucial phase in the development of perennial grasses and most flowering plants, signalling the changeover from vegetative growth to reproductive growth (Simpson and Caroline 2002). The applicable timing of anthesis is necessary for the plant’s adaptation to environmental stresses, as well as the completion of the plant’s life cycle (Curtis 1968). In agriculture, normal flowering is a prerequisite for crop production whether the seeds or vegetative mass are harvested, and it is regulated by multiple genetic factors that interact with environmental conditions (Craufurd and Wheeler 2009; Feng et al., 2017). Existing research on molecular biology has identified several critical pathways that play an important role in flowering regulation, such as the GA pathway, vernalization pathway, photoperiod pathway, and autonomous pathway (Mouradov et al., 2002). For most annual crops, the flowering time within a growing season is predominantly determined by the responses of temperature and photoperiod. Perennial crops, however, have an added vernalization requirement, and uncertain external environmental factors may lead to greater impact on the life cycle of perennial grasses. Hence an appropriate flowering time is strongly related to nutrient quality and forage yield (Bushman et al., 2012). For perennial forages, however, far too little attention has been paid to characterizing the flowering mechanisms.

Orchardgrass (Dactylis glomerata L.) is an important cool-season perennial forage grass that is cultivated and utilized worldwide. Indigenous to Eurasia and northern Africa, it has been naturalized on nearly every continent and utilized as a pasture or hay grass, which is important for the production of forage-based meat and dairy throughout the temperate regions of the world. As an excellent pasture and ecological improvement grass, orchardgrass has high biomass, abundant carbohydrates, shade tolerance, and broad adaptability (Volaire 2010). Heading date is a surrogate measure for flowering time and is strongly correlated with the yield and quality of forage grasses. Interestingly, due to the widespread geographical distribution in orchardgrass, its substantial variation in flowering timing provided a valuable source of germplasm to tease apart the
genetic mechanisms underlying flowering time regulation (Sheldrick et al., 2010). Therefore, in this study, we performed an integrated analysis to identify flowering genes based on transcriptome, QTL and BSA data, as well as detected potential regulators co-expressed with candidates. This research will contribute to our perception of the flowering adjustment of orchardgrass, further promoting selection in forage grass breeding.

Materials and Methods
An F₁ population of 213 individuals derived from the cross between two orchardgrass cultivars-‘Kaimo’ (early flowering time) and ‘01436’ (late flowering time)-was used for map construction and QTL. Plants were grown in the research field of the Grassland Science Department, Sichuan Agricultural University at Ya’an, Sichuan, China. Genomic DNA samples of the two parents and 213 F₁ progeny individuals were subjected to SLAF-seq with some modifications as described (Sun et al., 2013). Briefly, HighMap software was used for map construction and QTL analysis based on our previous report (Zhao et al., 2016). Significant loci associated with heading date and flowering time were identified based on LOD scores larger than the 5% cut-off value determined through 1,000 permutation tests.

To identify SNPs of genes involved in flowering time, 29 full-sib individuals from an F₁ mapping population of 213 lines were used for QTL sequencing. SNPs that were homozygous in one parent and heterozygous in the other parent were prioritized and extracted from the “vcf” output files. The homozygous genotype of the parent was used as the reference to calculate the number of reads of this parent’s genotype in the individuals in the offspring pools. The ratio of reads harbouring the SNP that was different from the reference sequence was calculated as the SNP index of the base site. Sliding-window methods were used to present SNP indexes across the whole genome. The SNP index for each window was calculated as the average of all SNP indexes in the selected window of the genome. The window size was set as 1 Mb, and the step size was set as 1 Kb. The difference in the SNP index of the two pools, namely, one earlier flowering pool and one later flowering pool, was calculated as the transformed Δ (SNP index).

Using the Arabidopsis thaliana homologues as queries, the putative flowering orthologous candidate genes in orchardgrass were identified by BLASTP with an E-value cut-off of 1e-5 (Bouché et al., 2016). If these genes were in common families in OrthoMCL, then their protein domains were predicted by Pfam (http://pfam.xfam.org/). Only genes that had the same protein domain as X were considered orthologous to the A. thaliana genes. To identify the differentially expressed genes and elaborated the expression pattern of candidate flowering genes, the expression data was extracted based on our previous research (Feng et al., 2017; Feng et al., 2018). The weighted gene co-expression network analysis was performed by using WGCNA package in R (v3.3.0) (Langfelder and Horvath 2008).

Results
Identification of flowering time genes in orchardgrass

In this study, 603 orthologues and paralogues in the orchardgrass genome were identified, corresponding to 210 flowering-related genes in the Arabidopsis thaliana flowering-time gene dataset (Bouché et al., 2016). Of these, 85 orchardgrass orthologues and paralogues corresponding to 53 flowering-related genes were differentially expressed between early- and late-flowering phenotypes of orchardgrass. Meanwhile, 25 and 5 were detected in the vernalization and photoperiod pathways, respectively. Several key flowering regulators such as the photoperiod related gene CO1, vernalization related genes VRN1 and VRN2, circadian clock related gene LUX1 and flowering integrator FT paralogue were differentially expressed between early- and late-flowering phenotypes, potentially contributing to the difference in heading date. Additionally, five FT orthologues might have undergone expansion during orchardgrass evolution, suggesting their essential roles in flowering time.

Flowering time gene mapping and expression analysis

To identify candidate genetic regions and key regulators associated with flowering time, we integrated QTL analysis and BSA with transcriptome expression-profiling data. The peak value for the transformed Δ (SNP index) localized to two regions spanning from 154.344 Mb to 156.231 Mb and from 157.05 to 159.599 Mb on chromosome 6. Based on the QTL results, we also identified a major locus at 157.639 Mb (np6325) on chromosome 6 that overlapped with the BSA candidate regions (Figure 1a). Fine-mapping analysis identified a 4.426-Mb overlapped region on chromosome 6 that may harbour the major locus contributing to orchardgrass heading date. After removing genes that were not expressed among the pre-vernalization, vernalization, post-vernalization, pre-heading, and heading stages, 30 candidate genes were predicted within this region (Figure 1b). Polymorphism detection identified
6 nonsynonymous SNPs corresponding to 4 candidates, including one \( FT \)-like gene and three MADS-box genes, in the early- and late-flowering populations (Figure 1c). In previous reports, the MADS-box family was revealed to be a highly conserved gene family involved in flowering time, floral organ formation and inflorescence architecture (Schilling et al., 2018). In the orchardgrass reference sequence, we identified 94 MADS-box genes, including 58 type I and 36 type II genes (Gramzow and Theissen, 2010). The MADS-box gene family was markedly expanded in the orchardgrass genome compared with other grass genomes, which likely drive the extensive variation in heading date and strong adaptability to environmental conditions of orchardgrass.

To investigate the gene expression of these four candidates, comparative transcriptome analysis was performed between the early-flowering and late-flowering orchardgrass lines. Gene DG6G02970.1 was the only significantly differentially expressed gene; this gene encodes the MADS-box gene \( AGL61 \)-like, which plays an essential role in pollen tube guidance and the initiation of endosperm development (Steffen et al., 2008). Mutants of the \( A. \) thaliana homologue AT2G24840.1 (\( AGAMOUS-LIKE 61, \ AGL61 \)) express female fertility reduction and defective central cells with abnormal morphology. \( AGL61 \)-like showed higher expression among five critical flowering stages in the early-flowering line than in the late-flowering line. Three nonsynonymous SNPs were identified in the \( AGL61 \)-like gene, resulting in changes from alanine to valine, alanine to threonine and glycine to valine (Figure 1c). Thus, DG6G02970.1 might participate in flowering regulation of orchardgrass.

WGCNA was used to search for candidate genes that were associated with flowering regulators. WGCNA revealed that DG6G02970.1 (\( AGL61 \)-like) is associated with a set of 114 genes in the early-flowering line. GO term enrichment indicated that carbohydrate metabolic process genes were particularly enriched, and glycolysis/gluconeogenesis pathway genes were enriched in the KEGG analysis. Among the biological processes, four terms related to carbohydrate metabolic process and two terms related to response to oxidative stress were highly enriched. The need for a high level of carbohydrates for enhanced flowering has been demonstrated. Carbohydrate accumulation is related to the transition from vegetative growth to flowering (Kozłowska et al., 2007). Assuming a conserved function of \( AGL61 \)-like in flowering regulation, we annotated genes that were differentially expressed in pre-vernalization stage versus post-vernalization stage or pre-heading stage versus heading stage comparisons in the early-flowering line. This analysis identified a potential relationship between \( AGL61 \)-like and the carbohydrate metabolic process. However, transgenic evidence needs to be provided to further confirm that the difference in heading date is caused by \( AGL61 \)-like alone or the cooperation of \( AGL61 \)-like and other co-expressed genes.

Figure 1: Genetic mapping of the orchardgrass flowering time candidate genes. (a) Mapping the flowering-time genes by BSA and QTL analysis. The transformed \( \Delta \) (SNP index) is the product of the \( \Delta \) (SNP index) and normalized SNP density in each 1-Mb sliding window (10-kb steps). The dark arrow and dashed line indicate the positions of the 1.89-Mb and 2.55-Mb peaks, respectively. (b) The clusters
and expression patterns of 30 candidate genes. The heatmap on the left side shows the expression of 30 candidate genes, the line chart on the right side show the expression pattern of clusters. (c) Exon-intron structure and nonsynonymous SNPs of four candidates in two phenotypes.

Discussion

Flowering regulation is a convoluted process for higher plants. A network consisting of more than 300 genes in Arabidopsis as only the tip of an iceberg in entire network of flowering-regulation (Bouché et al., 2016). In this research, 210 flowering-related genes were identified in orchardgrass, and further performed the comparison of expression patterns of these flowering genes. In addition, we found 50 potential flowering-related genes were differentially expressed between early- and late-flowering phenotype of orchardgrass, and most of these DEGs were enriched in photoperiod pathway and vernalization pathway. These results indicated there may be diversity in flowering regulatory networks among different species, but the key regulators that have significant impacted on flowering time are relatively conservative. Due to the complex genome organization, one or a limited number of differentially expressed flowering-genes may not have a decisive influence on flowering time of orchardgrass. Whereas the cumulative effect of many differentially expressed verified flowering genes or novel genes may be an important reason for the flowering time diversity of orchardgrass. Furthermore, four main candidates were identified as key regulator via the combination of transcriptome, QTL and BSA data. Of which, three nonsynonymous SNPs may result in distinct expression patterns of $AGL61$-like in early- and late-flowering phenotype of orchardgrass. The functional studies of $AGL61$ suggest a role in female gametophyte development, embryo sac development and early seed development (Bemer et al., 2008). Our results indicated that $AGL61$-like may play a similar function in development regulation of orchardgrass. In future studies, more flowering time regulating genes will be identified and validated by using known flowering regulators and hub genes involved in the gene network constructed by WGCNA.

Acknowledgements

This research work was funded by the National Basic Research Program (973 Program) in China (No. 2014CB138705), the National Natural Science Foundation of China (NSFC 31872997), the Earmarked Fund for Modern Agro-industry Technology Research System (No. CARS-34) and the National Project on SciTec Foundation Resources Survey (2017FY100602).

References


BRS Quênia and BRS Tamani: new *Panicum maximum* Jacq. hybrid cultivars in Brazil


1Embrapa Beef Cattle, Rua Rádio Maia, 830, Campo Grande, MS, Brazil; Embrapa Acre, Rio Branco, AC, Brazil; Embrapa Cerrados, Planaltina, DF, Brazil

Key words: cattle performance; forage; guineagrass; quality; yield

Abstract

Since 1982 Embrapa Beef Cattle in Campo Grande, MS, Brazil, develops a *Panicum maximum* Jacq. breeding program, based on the germplasm collected and assembled by IRD (Institut de Recherche pour le Développement) and received through a cooperation-agreement with IRD. The germplasm was evaluated and four cultivars were released directly from the germplasm: cultivars Tanzania, Mombaça, Massai and BRS Zuri. Breeding began in 1990 and involved crosses between sexual plants and selected apomictic accessions. The program consists of evaluation followed by selection of hybrids in plots with replications, evaluation of the selected hybrids in national network experiments in diverse regions and then evaluation of the few selected hybrids under grazing. Hybrids are also evaluated for disease and insect resistances and abiotic stresses. Seeds are multiplied between each evaluation phase. The whole process takes from 10 to 20 years for the release of superior cultivars. Recently, Embrapa released two hybrid cultivars. BRS Tamani, a short, very leafy and high-tillering cultivar, and BRS Quênia, a medium height, very leafy productive cultivar. Both cultivars are recommended for medium to high fertility light soils, corrected for soil nutrients, and for rotationally grazed management. BRS Quênia, because of its short stature and quality is well indicated for cattle weaning. Both cultivars are tolerant to all the spittlebugs present in Brazil. They are not suited for waterlogged soils. Compared to the traditional cultivars in Brazil, these two cultivars showed improved digestibility and crude protein and greater animal daily gains and BRS Quênia also provided higher liveweight gain per area.

Introduction

Brazil maintains the largest cattle herd in the world, is the second largest meat producer and the world’s leading meat exporter. The cattle herd with 213.68 million heads (Abiec 2020) is basically kept on pasture, since only 14% is finished in feedlot (Abiec 2020). This is the great differential of the meat produced in Brazil, which gives a competitive advantage to exports because it is less expensive, free from the risks associated with mad cow disease (bovine spongiform encephalopathy), in addition to providing greater animal welfare.

To maintain this entire herd (on 162.5 million hectares of pasture), several forages are part of the production systems, and the search for new, more adapted, productive and better-quality forages is constant. To meet the demand for improved cultivars, Embrapa Beef Cattle maintains programs for the development of cultivars of *Brachiaria* spp. (syn. *Urochloa* spp.) *Panicum maximum* (syn. *Megathyrsus maximus*) and *Stylosanthes* spp., to meet the demand for improved cultivars.

The *P. maximum* breeding program began in 1982 with the import from France of its entire germplasm collection representative of the species’ natural variability (Savidan *et al.*, 1989). French researchers from the IRD (Institut de Recherche pour le Développement), formerly ORSTOM (Office de la Recherche Scientifique et Technique d’Outre-Mer) collected natural variability at their Centre of Origin in Kenya and Tanzania in 1967 and 1969 (Combes and Pernès 1970), and after thorough studies of variability, agronomic potential, reproductive mode and inheritance of the mode of reproduction, among others, the collection was made available to the tropical world.
In Brazil, the entire collection was evaluated agronomically and morphologically between 1984 and 1989 (Jank et al., 1997; Savidan et al., 1989) and the first crosses were carried out from 1990. At that time, the cultivar in use in Brazil was the widespread cv. Colonião. Approximately 50% of the accessions in the introduced collection were more productive than this cultivar (Jank 1995) and thus, after several studies, the cultivars Tanzania-1 in 1990, Mombaça in 1993 and Massai in 2001 were commercially released. These cultivars rapidly gained the preference of the cattle rearers in Brazil. Approximately 50% of the accessions in the introduced collection were more productive than this cultivar (Jank 1995) and thus, after several studies, the cultivars Tanzania-1 in 1990, Mombaça in 1993 and Massai in 2001 were commercially released. These cultivars rapidly gained the preference of the cattle rearers in Brazil. All of this was combined with the fact that these cultivars had a good seed production, which enabled commercial production and distribution to ranchers.

Later, with the continuation of the improvement program, the released cultivars included BRS Zuri in 2014 and the hybrids BRS Tamani in 2015 and BRS Quênia in 2017, all registered and protected with the Ministry of Agriculture, Livestock and Supply in Brazil. The objectives of the present paper are to show the steps that were taken to the selection and release of the two hybrids developed and released in Brazil.

Materials and Methods

The research was developed by Embrapa Beef Cattle in Campo Grande, Mato Grosso do Sul, Brazil, in partnership with various other Embrapa Units throughout the country. The *P. maximum* breeding program follows three phases: phase 1 - evaluation of many accessions and/or hybrids in small plots; phase 2 - evaluation of the selected ones in network trials in different regions; phase 3 – evaluation under grazing.

Crosses between a selected sexual plant and two distinct apomictic accessions were carried out in 1990 at Embrapa Beef Cattle. All hybrids obtained from these crosses were planted in 1991 in the field at 1 m spacing between plants. A visual selection was carried out with 10% selection pressure and the best 79 hybrids were evaluated in phase 1 in 1995. Plots consisted of two lines of five plants each, spaced 0.50 m between lines and plants, with two replications under cuts every 35 days in the rainy season and one cut at the end of the dry season (Jank et al., 2001; Resende et al., 2004).

Four selected hybrids, accessions from the germplasm bank and standards in a total of 23 genotypes were evaluated in network trials (phase 2) in six states in Brazil: Acre, Rondônia, Federal District, Mato Grosso do Sul, Rio de Janeiro and Rio Grande do Sul (Jank et al., 2004; Ledo et al., 2005; Valentim et al., 2006; Montardo et al., 2010; Fernandes et al., 2014). Experiments consisted of 23 genotypes evaluated on 6 x 4 m plots, with three replicates in a randomized block design.

Hybrid H46 (BRS Tamani) was evaluated for animal performance (phase 3) in the Cerrado Biome (Maciel et al., 2018) in comparison to cv. Massai in an experiment under rotational grazing system with 56 days grazing cycle (28 days of grazing and 28 days of rest).

Also, in phase 3, hybrid H64 (BRS Quênia) was evaluated for animal performance in the Amazon Biome in Rio Branco, AC, from 2010 to 2012, with cv. Tanzania as standard. It was also evaluated in the Cerrado Biome in Campo Grande, MS, from 2011 to 2014, with cv. Mombaça as standard. At each location, cv. BRS Quênia and the standard were planted on 3 hectares (2 replications of 1.5 ha each).

Other evaluations were also done leading to the selection of the cultivars, such as tolerance to spittlebugs, resistance to diseases (viruses, leaf spot and seed fungi occurrences), seed production, fertilization responses, and tolerances to poorly drained soils, shade and frost.

Results

**BRS Tamani**

In phase 1, cv. Tamani presented 18 t/ha of total dry matter yield and 15 t/ha of leaf dry matter yield, while in the dry season its production was 10% of the annual production.

In the phase 2, in the mean of the five evaluation experiments, cv. BRS Tamani produced 11.2 t/ha and 1.24 t/ha leaf dry matter yields in the rainy and dry seasons, respectively, with a crude protein content of 12.4% and 10%, respectively. Leaf digestibility was 60% in all seasons.

In phase 3 under grazing evaluating Nelore young bulls, with no supplementation, in the Cerrado Biome, BRS Tamani resulted in gains of 791 g/animal/day in the rainy season and 311 g/animal/day in the dry season. The liveweight gain per area was 2.28 kg/ha/day.
**BRS Quênia**

In phase 1, cv. BRS Quênia showed a production of 19 t/ha of total dry matter and 14 t/ha of leaf dry matter, and in the dry season its production corresponded to 14.7% of the annual production.

In phase 2, in the mean of the five evaluation experiments, cv. BRS Quênia produced 13.2 and 1.41 t/ha with 11.8% and 10.6% crude protein and 60 and 64% digestibility in the rainy and dry seasons, respectively.

In phase 3 under grazing, in the Cerrado Biome, BRS Quênia resulted in 258 kg/animal/ha in the dry season and a gain of 975 kg/ha. Mean crude protein and digestibility were 11.7% and 54.4%. In the Amazon Biome, BRS Quênia resulted in 700 g/animal/day gain in the rainy season and 643 g/animal/day in the dry season. This resulted in an animal gain of 862 kg/ha. Mean crude protein and digestibility were 13.6% and 63.5%, respectively.

**Discussion**

**BRS Tamani**

BRS Tamani was selected in the first phase because of its short stature, quality, agreeable visual appearance due to abundance of soft leaves, high tillering capacity, rapid regrowth after cuts and seed production. It is not as productive as cv. Massai, the commercial wide-spread cultivar of the same stature. In phase 2, in the mean of the five network experiments, it was 12 to 18% less productive, but presented 4 to 7% higher leaf percentage, 6 to 13% more crude protein and 3 to 7% more digestibility than cv. Massai (unpublished data).

These characteristics were ascertained under grazing, where BRS Tamani showed an 8 to 9% lower carrying capacity than cv. Massai, but a 11 to 18% higher liveweight gain per animal. Gains per area were very similar for both cultivars (Maciel et al., 2018; Braga et al., 2019). Thus, the high quality of cv. BRS Tamani was fundamental for this high gain per animal. In the rainy season, crude protein and digestibility were 20% and 9% higher for BRS Tamani, respectively, while in the dry season they were 9% and 6% higher.

BRS Tamani also showed an important advantage. Since it is early-flowering (it flowers in February during the rainy season), the animals control flowering through grazing, and so it enters the autumn-winter season with still a high-quality forage (Braga et al., 2019). In June, its digestibility was 66%, 9% higher than cv. Massai which flowers in April-May in the beginning of the dry season and loses much of its quality.

Another advantage is its short size which, together with the high leaf percentage and short abundant stems, permit an ease of management and greater flexibility of use, which is very important for cultivars of this species, which are usually difficult to manage. For *P. maximum* cultivars, rotational grazing is recommended, with entry of animals at 50 cm of canopy height and exit at 25 cm from the soil (Pasto Certo 2020) or entry 35 cm and exit 25 cm as suggested by Tesk et al. (2019). BRS Tamani also shows a good ground cover. It is, however, not adapted to waterlogged soils (Andrade and Valentim 2009).

**BRS Quênia**

BRS Quênia was selected in the first phase because of its visual appearance, medium-high stature, abundance of soft leaves, thin abundant stems, quality and productivity. In the mean of the five network trials in phase 2, BRS Quênia was from 3% to 9% more productive than cv. Mombaça in the rainy and dry seasons, respectively. Cv. Mombaça is the most planted cultivar in Brazil, and is slightly taller than BRS Quênia. Its quality was greatly superior than that of cv. Mombaça in the dry season, 19% and 15% greater crude protein and digestibility, respectively. In the rainy season, the superiority was 10% and 5%, respectively (Jank et al., 2017).

These positive characteristics were also ascertained in the grazing experiments (Andrade et al., 2013; Jank et al., 2017). In the Cerrado Biome, BRS Quênia presented a 17% higher animal gain/ha than cv. Mombaça (Jank et al., 2017). The carrying capacity was similar between cultivars, regardless of the season, thus, the superiority was due to a better individual performance. This gain was mainly due to its high quality, 7% and 14% higher crude protein and 4% and 8% higher digestibility in the rainy and dry seasons, respectively.

In the Amazon Biome, carrying capacity of cv. BRS Quênia was lower than cv. Tanzania during the rainy season, as a result of the soil waterlogging in the experimental area in the months of January and February, in the two years of study, a situation that most affected cv. BRS Quênia than cv. Tanzania, which has a higher tolerance to soil waterlogging (Andrade and Valentim 2009). Even so, the greater weight gain per animal offset the lower carrying capacity of the pastures of cv. BRS Quênia, resulting in a liveweight productivity 8% higher than for cv. Tanzânia.

BRS Quênia shows similar advantages as BRS Tamani of the high quality in autumn-winter, because it is also early flowering. Despite its taller stature, it is easier and more flexible to manage than Tanzânia and Mombaça. It is recommended...
for rotational grazing, with entry canopy height of 70 cm from the soil and exit 35 cm from the soil (Jank et al., 2017) or even entry height 55 cm and exit height 35 cm from the soil (Tesk et al., 2019).

Summarizing, BRS Quênia is a grass with high forage quality and high yield potential when cultivated on well-drained soils, being especially suitable for intensive animal production systems. The main differential of this cultivar in relation to the traditional cultivars Tanzania and Mombaça is the best plant architecture, with smaller clumps, higher density of soft green leaves and tillers, tender stems and lower percentages of dead material, facilitating grazing management and maintenance of the pasture structure more favourable to the high consumption of forage by cattle.

BRS Tamani is a short grass with a high forage quality when cultivated on well-drained soils, provides for an excellent ground cover conferring ease and greater flexibility of management. It is an option for high-input pasture systems concerning cattle growing and fattening. There are also reports from farmers of its suitability for sheep and horse grazing.

Both cultivars are resistant to the Brazilian spittlebugs and are indicated for use in well-drained soils of medium to high fertility, with more than 800 mm of annual rainfall and up to six months of dry season. However, they do not tolerate waterlogged soils.

Acknowledgements
The authors would like to acknowledge Embrapa and Unipasto (Association for the Promotion of Research in Forage Breeding) for financial support and CNPq for the first author’s “Productivity in technological development and innovative extension” scholarship.

References


Identifying forage quality Eastern gamagrass [Tripsacum dactyloides (L.) L.] genotypes from a wild regional collection

Hollowell, D.M.; Morrison, J.I.; Baldwin, B.S.

Department of Plant and Soil Sciences, Mississippi State University, MS, USA

Key words: North American native grass; selection; digestibility; southeast United States

Abstract
Eastern gamagrass is a perennial warm-season grass native to North America and endemic to the eastern United States. The species is highly valuable as both a forage and hay crop. In 2012, 171 wild-type eastern gamagrass accessions were collected from the southeast, mid-Atlantic and Atlantic coast regions. Each accession was relocated to Starkville, MS (33.423585, -88.792394) and established in a long-term nursery. Accessions were analyzed for ploidy level and during 2013-2014 were further evaluated for desirable forage characteristics, including cold tolerance, delayed maturity, rust resistance, and digestibility. Fourteen elite individuals were identified from the original collection and were propagated for further research. Elite genotypes were divided into individual proaxes and transplanted into an RCB design with three replications. Plots measured 3.04 m x 1.21 m with five replicate plants evenly spaced within the plot. Following a one-year establishment period, whole plots were harvested on a 28-day cycle from May to October. Plots were harvested to a 15 cm stubble height with a Wintersteiger Cibus S harvester. Following each harvest, nitrogen fertilizer was applied to all plots at 56 kg N ha⁻¹ using urea ammonium sulfate (32-0-0-12S). Homogenized subsamples were taken to determine per cent dry matter, neutral detergent fibre (NDF), acid detergent fibre (ADF), and in-vitro dry matter digestibility (IVDMD). The commercial cultivar ‘Highlander’ was included in the study as a check. Seasonal yields ranged from 1.19 - 2.73 Mg ha⁻¹. Originally collected in Alabama and North Carolina, three accessions produced significantly greater forage yield than the check (P> 0.0001). Digestibility of the commercial check as well as one accession – collected in Tennessee – was significantly greater than all other accessions (P> 0.0001).

Introduction
Eastern gamagrass is primarily used as a forage to be grazed but is also useful as hay or silage (Salon and Cherney 1999). Proper management is vital to successfully maintaining gamagrass, as livestock often overgrazes due to its high palatability. Overgrazing by livestock is believed to be the initial cause of declining natural stands of eastern gamagrass (Rechenthin 1951). Many current commercially available cultivars were originally collected from wild stands in the Midwest region of the United States. At the initiation of this research, no extensive collections of gamagrass germplasm had been conducted throughout the southeast. The original collection described herein was conducted to assemble a diverse collection of wild-type germplasm adapted to the climate of the southeast United States. Gamagrass can be either diploid or tetraploid, with diploid being highly desirable for breeding due to the possibility of sexual recombination. This is not possible in tetraploid genotypes as they are predominantly apomictic. It is hypothesized that most native diploid stands of gamagrass are found in the Great Plains region of the United States, while most stands found in the southern U.S. are believed to be tetraploid. Diploid populations have been confirmed in Texas and Florida (Newell and de Wet, 1974). This study was designed to identify any potential accessions that possess the necessary characteristics to be a high forage quality cultivar, including; cold tolerance, digestibility, rust tolerance and delayed maturity(P> 0.0001). Digestibility of the commercial check as well as one accession – collected in Tennessee – was significantly greater than all other accessions (P> 0.0001).

Methods and Study Site
For this experiment, from April 2012 to August 2012, 171 accessions of eastern gamagrass were collected from wild native stands across eight states in the southeast, mid-Atlantic, and Atlantic coast regions. Proaxes were harvested from the
native stands and transported to Mississippi State University (Starkville, Mississippi). The samples were then transplanted into a nursery block with a 1m x 1m grid arrangement at the Henry H. Leveck Animal Research (South) Farm (33.423756, -88.791594). During 2013 and 2014, evaluations were conducted via visual ratings on all individuals in a nursery for desirable forage characteristics such as disease resistance, cold hardiness, and the onset of reproduction. Seven individuals failed to survive the winter following the 2014 growing season. From 28 October to 1 November 2014, ratings for foliar rust (the main pathogen of interest being southern corn rust (Puccinia polysora)). Plants were assigned a rating of 1 to 5: 1) No disease present 2) Very few, faint lesions totalling less than 25% coverage of plant 3) Moderate rust infestation, total coverage not exceeding 50% of plant material 4) Abundant rust and fungal lesions, covering more than 50% of leaf tissue 5) Complete infestation, entire plant displaying rust spores or fungal lesions.

The next screening conducted was for cold hardness. On two separate dates, 20 November and 5 December, individuals were evaluated five days following overnight ambient air temperatures of -5°C. Plants were assigned a rating of 1 to 5: 1) Severe leaf tissue damage, complete loss of tissue structure 2) Widespread leaf tissue damage and loss of colour to greater than 50% of total leaf area 3) Moderate tissue damage and loss of colour on up to 50% of total leaf area 4) Minimal leaf tip damage and some loss of colour to less than 25% of total leaf area 5) No presence of damage to leaves.

Visual ratings for rust resistance were significantly affected (P< 0.0001) by individuals in the population. Mean raw data values ranged from 5.0 – 1.0 (LSD = 0.9278), with an overall raw mean of 2.9 and a median of 3. Mississippi accessions were among the most severely infested individuals in the entire collection. Of the lowest-ranked (highest rust infestation) mean separation, Mississippi accessions comprised 71% (10 of 14) of that group, while the highest-ranked (lowest rust infestation) mean separation group is 35% (7 of 20) Mississippi accessions.

**Cold Tolerance**

Evaluation of cold tolerance ratings showed that genotype had no significant effect (P=0.7264) on cold tolerance rating (LSD=2.168). Mean cold tolerance ratings ranged from 1.0 to 4.0, with a mean rating of 2.5 and 1.3 in November and December, respectively. The median rating for November was a 3, while December was 1.

**Onset of Reproduction**

The onset of reproduction began in May and continued through June. By the 5th week of June, all entries had initiated reproduction. The overall mean date of initiation of reproduction was week 3.07. Results were divided by state of origin and week of maturity initiation. A total of 21 entries were collected from the state of Alabama. Of those individuals, the mean flowering date occurred later (0.93 weeks) than the overall population mean date of initiation. Accessions from Arkansas (5) had a mean date of initiation of reproduction of 1.8 weeks, 1.27 weeks earlier than the overall population mean. Accessions from Arkansas (5) had a mean date of initiation of reproduction of 1.8 weeks, 1.27 weeks earlier than the overall population mean.
of maturation date of 2.1 weeks, much earlier than the overall population mean.

**Forage Digestibility**

Individual plants in nursery showed significant differences (P < 0.0001) in forage digestibility, shown as IVTDMD (LSD = 2.67). IVTDMD of forage samples ranged from 50.2% - 76.3%, with an overall mean of 64.5 and a median of 65.2. Of the 14 elite genotypes, the accession from Tennessee showed significantly higher IVDMD compared to the others and equal to the commercial check.

When looking at the elite 14, all accessions had comparable yields to the commercial check. However, two from Alabama and one from North Carolina, three accessions showed yields significantly greater than ‘Highlander’.

**Discussion [Conclusions/Implications]**

From these, 14 individuals were determined to be elite and were propagated for further research, along with a check of the commercial variety Highlander.

Despite notable differences in phenotypic characteristics, all collected accessions were determined to be tetraploid. Therefore, morphological characteristics such as leaf width, leaf colour, and spring growth earliness used previously to differentiate diploid individuals from tetraploid individuals (Dunfield 1986) could not be used for stands in the southern and Atlantic regions.

Of the 14 selected elite genotypes, five were originally from Mississippi, three from Alabama, two from South Carolina, and one from Georgia, North Carolina, Arkansas, and Tennessee. Of the 14 elite genotypes, the accession from Tennessee showed significantly higher IVDMD compared to the others and equal to the commercial check. However, when looking at yield for the elite 14, all accessions had comparable yields to the commercial check, with three accessions, two from Alabama and one from North Carolina, showing yields significantly greater than ‘Highlander’.

This collection’s complete lack of any diploid germplasm supports the long-held hypothesis that is naturally occurring wild-type stands throughout the southeast are predominantly tetraploid. While the absence of diploid germplasm from this collection also makes selection breeding difficult, some sexual recombination is achieved in tetraploid gamagrass, preserving the possibility of genetic improvement (Dewald and Kindiger 1998).

**Acknowledgements**

We would like to thank the Mississippi Agriculture and Forestry Experiment Station for supporting this research and all staff and student workers for their hard work and dedication in furthering this research.

**References**


Dunfield, P.C. 1986. Characterization of eastern gamagrass populations from Northeast Texas. In: The prairie: roots of our culture; foundation of our economy: *Proc. of the Tenth North American Prairie Conf. of Texas. Women’s University, Denton, Texas, June 22-26, 1986*


THEME 3: LIVESTOCK PRODUCTION SYSTEMS

Topic: Social-economics of livestock production systems
Involving stakeholders in crop-livestock systems analysis: Innovation Platforms in Burkina Faso and Niger, West Africa

Bado, V.1; van Rooyen, A.2; Umutoni, C.1; Whitbread, A.3.

1 The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), PB 12404 Niamey, Niger.
2 The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), PO Box 776 Bulawayo, Zimbabwe.
3 The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), C/O- IITA East Africa Hub, P.O. Box 34441, Dar es Salaam, Tanzania.

Abstract

The development of markets and agricultural productivity need participative research approaches that involve farmers, stakeholders and actors in the value chains of agricultural products and inputs. This study illustrates the use of multi-stakeholder platforms to address critical issues that often curtail effective implementation of development strategies and achievement of objectives. The process used to facilitate stakeholder participation and achieve enhanced understanding of collective actions to achieve objectives is illustrated by case studies in Niger and Burkina Faso. The process that determines the causal relationships among the various problems is also presented; results from the process can be used to determine entry points for addressing system challenges. Finally, the study offers specific insights and analysis related to small-ruminant and feed value chains within Niger and Burkina Faso. The strengths and weaknesses of each node of the value chain are assessed and appropriate upgrading, management, and development strategies suggested. Entry points for action and strategies for intervention are identified to improve functioning of the crop-livestock value chain and the productivity of agro-pastoral farming systems. Participative analysis and understanding of the functioning of agricultural value chains enable farmers and actors to improve agricultural productivity and marketing. The multi-stakeholder platform approach is a more suitable tool for socio-economic analysis of integrated systems, and identification and implementation of development strategies, than traditional disciplinary research approaches.

Introduction

In the drylands of the West African Sahel (WAS), especially in both Burkina Faso and Niger, there is high potential to increase the quantity and diversity of animal-sourced food production. To unlock this potential, these countries will have to address a range of barriers and challenges. The growing human and livestock populations generate high pressure on cultivated lands and rangelands. This pressure, together with increasing climatic stress, results in increased tension between pastoral and agricultural communities. Experience in and knowledge of these complex agricultural systems may tempt people to point out obvious problems and to select the best technological fixes to redress these problems. However, this assumed “knowledge” often results in the proposal and implementation of simple solutions with individual technologies that are based on linear thinking (van Rooyen et al., 2020) without taking into account the context and socio-economic constraints.

A realistic approach to improve the complex agro-pastoral systems that provide the well-being of rural populations should first analyze the constraints and challenges that limit the production, the development of local markets for agricultural products and specific actions that could stimulate the development of crop-livestock value chains (Nederlof et al., 2011). Systemic challenges in the complex crop-livestock value chains can only be unlocked if the interrelationships among the problems are addressed. This requires addressing both technical and socioeconomic issues within their specific contexts while ensuring the cooperation and commitment of a range of stakeholders. Instead of individual approaches, this research aims at identifying strategic interventions, from
production to market, which could facilitate both the functioning and development of crop-livestock value chains. We hypothesized that global and participative analysis of crop-livestock production systems with farmers and stakeholders should identify strategies and context-specific actions that should be implemented to improve the productivity and the marketing of agricultural products. The novelty of this study is the use of the multi-stakeholder platform approach to identify strategic interventions for improving the functioning of agricultural value chains enabling actors to improve productivity, marketing and incomes for mutual benefits.

Materials and Methods
Two countries representative of the WAS (Burkina Faso and Niger) were selected for this study. Within each, two research sites were selected for a total of four sites (Torodi and Maradi in Niger and Korsimoro and Sampalga in Burkina Faso). The research involved a baseline survey and implementation of innovation platforms (IPs) in the four sites. The baseline survey involved 191 and 200 households in Niger and Burkina Faso, respectively, to solicit descriptions of the production systems and crop and livestock value chains (CL-VC) of the areas. The IP implementation process involved the primary stakeholders in the following stages: (I) stakeholder identification, (II) problem diagnosis and possible solution identification, (III) value-chain analysis, and (IV) identification of entry points of intervention (Figure 1).

![Figure 1: Four-step approach used to establish Innovation Platforms in four sites within the two countries, Niger and Burkina Faso (source: authors)](image)

Results

**Key findings from the baseline survey**

Our findings indicated that households owned, on average, 3.7 ha in Niger and 3.6 ha in Burkina Faso. Female-headed households owned less land than male-headed households. Millet and sorghum were the primary cereal crops while cowpea and groundnut were the primary legumes crops. Crop residues were the primary food fed to animals in both Niger and Burkina Faso. Almost all (99% and 100%) households (99% and 100% in Niger and Burkina Faso, respectively) kept livestock for cash income and to purchase food in case of crop failure. Only 33% and 42% of farmers in Burkina Faso and Niger, respectively, were members of farmers’ organizations. Access to formal credit was a constraint to households in the four study locations, especially in Korsimoro. As an alternative, many households sought credit through informal sources. Households reported that their involvements in crop-livestock activities were based on concerns about food security and source of income. In Niger and Burkina Faso,
respectively, approximately 75% and 86% of households explained their involvement in crop-livestock activities as due to the need to secure food for their households’ consumption, and 13% and 24% reported that their involvement was to earn income.

**Innovation platform process**

**Stakeholder identification:** Stakeholders were identified during discussions with local government, extension personnel, NGOs, traditional leaders, and known farmer groups or associations. Care was taken to involve critical players within the production system: farmers and their associations or local structures, input markets, butchers, support services (extension, veterinary), and local market players.

**Problem identification:** System challenges included access to inputs, feed shortages, poor veterinary care, low prices, and poor markets, as well as lack of knowledge and access to credit. Feed shortage was the primary challenge constraining livestock-value chains for all sites. Animal diseases, as well as the high mortality of animals, were also reported as significant obstacles to livestock production. The other common challenge to the development of crop and livestock value chains was the lack of, or weakness within, organizations, especially farmers’ organizations. Crop-livestock value chains have been constrained by the low technical capacity of the stakeholders involved. Common marketing problems included poor market organization, low product prices, and lack of opportunity to access international and/or regional markets. In most cases, access to external markets was an obstacle. Another constraint in crop-livestock value chains was institutional gaps.

**Relationships between problems:** In the systemic approach to problem analysis we determined interdependencies among problems. Identifying linkages between challenges clearly illustrated the strong relationships among market, inputs, production, and weak knowledge. If the market does not function well, farmers do not have the resources to purchase farm inputs. The limited access to inputs impacts farm productivity negatively and results in fewer products, which are also of lower quality, that are delivered to the market. Analysis also indicated that inputs and capacity-building were strongly related. With limited inputs, capacity-building that relies on the use of inputs will not be vigorous enough to benefit stakeholders. Conversely, inputs without knowledge about how to use them are not useful either. The market is also related to financial resources. If the market does not function, stakeholders cannot find a way to repay their depts. Access to credit has a significant impact on farm productivity. Farmers facing severe capital constraints tend to use lower levels of inputs in their production activities.

All of the challenges identified were linked to organization in some way. Stakeholders without organization impact the system at different nodes of the chain. The system will not function effectively if contributors do not organize themselves well enough to buy inputs, to sell products, to build capacity, and to access credit.

If the system overall does not work, there will be less tax revenue and the government will not have as many resources to invest in infrastructure, including agriculture and livestock infrastructure, roads, and more. Examining the relationships connecting challenges places problems within a larger context, illustrating clearly that addressing individual problems will not result in systemic and sustainable change.

**Value-chain mapping from the Innovation Platform meeting**

Analysis showed that the feed and small ruminant value chains were not well-structured. The primary actors involved in the feed value chain included: (i) feed-input suppliers who controlled the supply of imported and locally produced feed inputs; (ii) feed producers; (iii) feed marketers and traders; (iv) feed processors (in many cases, groups of women who chop cereal grain stover and sell the chopped roughage or mixed feeds locally); and (v) livestock farmers. The main stakeholders involved in small ruminant value chain were: (i) Producers, mainly farmers and groups of women engaged in sheep and goat production and fattening; (ii) Aggregators/livestock traders (private traders who collect animals from farmers or local market); (iii) Meat processors (butchers, small-scale processing units that produce meat and Kilishi, a popular sun-dried and seasoned meat consumed and sold in local markets in Niger); and (v) consumers. Lack of organization, lack of capacity and weak institutions/policy were the main constraint on the development of both feed and small ruminant value chains in Niger and Burkina Faso.

**Entry points for action to improve crop-livestock value chains**

In Torodi (Niger) capacity-building must address the skills required by farmers and other support services. It should pay particular attention to production technologies, the establishment and support of markets, and the skills farmers need to access credit. Helping farmers organize
themselves to access input and output markets, and establishing functional farmer organizations, can serve as strategic entry points. In Maradi (Niger), production and markets were also identified as important entry points, but here access to credit and interest in becoming more commercially oriented were also highlighted. Analysis showed that farmers’ organizations should be at the center of all activities for the best impact, since the primary issue underlying all constraints was the lack of organization of the various stakeholders involved in the crop-livestock value chains.

In Burkina Faso (Korsimoro and Sampelga) improving production, resolving market-related problems, and infrastructure and equipment factors should be entry points for innovation platform activities. Planning smart marketing activities has been seen as an innovative way to boost producers’ market opportunities.

Discussion [Conclusions/Implications]

Innovation platforms have gained momentum as positive factors in agricultural development. Their strengths lie in the participatory and multi-stakeholder approach, which relies on cognitive diversity and the collective identification of problems, innovation around solutions, new actor constellations, and transition toward improvements of the system (Nederlof et al., 2011). This research has shown that diagnosing problems is key in innovation platforms.

The process of diagnosing problems helps IP participants obtain a solid understanding of the full system and pushes them to approach system challenges in innovative ways, and as a team rather than as individuals operating in isolation. The identification of constraints and opportunities helps to narrow the focus of the platform.

We found that determining the interdependencies among the “problems” provided insights into the systemic challenges crop-livestock systems face. To be successful, all parties need to attend and cooperate in IPs. Building a common vision is an essential step for the success of any IP. In short, the incentives to change behavior need to be very clear. Therefore, interventions must start by addressing the dynamics among the major problems and ensuring that there are functional feedback mechanisms among them. Investments in production must have a clear return in the marketplace. Profit increases drive the adoption of technology, not just increases in production (see Michler et al., 2019).

The most important task in system analysis is to determine which activities must be engaged in a project to improve the flow of information, resources, and interactions among the components and stakeholders in the system. To facilitate this process, our study asked the following questions: Who are the stakeholders that can address the problem? What do they need, or what elements must change (information, capacities, resources, linkages), or what needs to change to resolve the root causes of the problems?

This study illustrates the value of problem analysis within a systems-thinking framework for identifying key entry points for improving value chains. The systems-thinking literature stresses that interventions aimed at the parts, or components, of the system will have limited impact and, at best, result in incremental change. The interactions, integration, and interdependencies among the parts of a system determine its behavior. Therefore, interventions aimed at intersection points are much more likely to bring about transformational change. Constructing influence diagrams that illustrate the relationships among the parts of the system and associated problems reveals the systemic nature of the problems. Embedding these diagrams into conceptual models of the system facilitates the identification of strong leverage points for interventions, avoiding linear reactions to problems.

Acknowledgements

This research was funded by the United States Agency for International Development (USAID) under the Feed the Future Innovation Lab on Livestock Systems program [PTE Federal Award No: AID-OM-L-15-00003] and the CGIAR research program Grain Legumes and Dryland Cereals (GLDC) conducted with support from the CGIAR Trust Fund and through bilateral funding agreements.
References


Food security in crop, livestock and mixed farming systems in Mali

Reiber, C.1; Carbajal, A.1; Traoré, S.1; Birner, R.1; Chagunda, M.1

1 Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute), Hohenheim University, Germany

Key words: food security; farming systems; livestock; nutrition

Abstract
This study evaluates the food security status, its determinants and the coping strategies in crop, livestock and mixed crop-livestock systems in southern Mali. Interviews were conducted with 258 households that were categorized into the three farming systems based on the revenue from livestock and crop production. A linear mixed model was used to analyse the effects of household characteristics on food security using the food consumption score (FCS), household dietary diversity score (HDDS), a modified household food insecurity access scale (mHFIAS) and coping strategies as indicators. Food consumption score was significantly influenced by the farming system with highest FCS for the livestock system (88) followed by the mixed system (77) and the crop system (69). Moreover, FCS was positively influenced by the number of crops cultivated, total farm milk production, off-farm income and number of raised chickens (p<0.1). The main difference in food intake between systems was for milk with average daily consumption of 201 ml, 110 ml and 60 ml in the livestock, mixed and crop systems, respectively. HDDS was also significantly influenced by the farming system with highest HDDS values for the livestock system (8.9), followed by the mixed system (8.2) and the crop system (8.0). Further, HDDS was positively influenced by crop diversity and number of chickens, and negatively influenced by the number of family dependents. During the food shortage period of August, households from the crop system were more food insecure than households from the mixed and livestock systems with mHFIAS values of 0.9, 1.5 and 4.3, respectively. Livestock and mixed systems were more resilient to food insecurity situations than the crop system. This study confirms the direct effect of milk production on milk consumption and the importance of livestock for enhancing food security and livelihood resilience.

Introduction
Despite many political and financial efforts in recent decades, the prevalence of food insecurity, undernourishment and (hidden) hunger in developing countries is still increasing. Projections show that the world is not on track to achieve Zero Hunger by 2030, or to meet global nutrition targets. This is particularly valid for Africa. Reasons include political, health and climate change crises (FAO et al., 2020).

Farming systems are fundamental for achieving food security by increasing the quantity and diversity of food within the household, providing the primary source of income and enhancing biodiversity to support the resilience of agroecosystems. Smallholder farmers are therefore the backbone of food security as well as economic, environmental, social and political stability in many regions. Food supply in less developed countries of the tropics and subtropics is dominated by small-scale mixed crop-livestock agriculture. In African agriculture, mixed crop-livestock systems provide most of the staples consumed: 90% of the milk, 80% of the meat, and 41-86% of grains like maize, rice, sorghum and millet (Thornton and Herrero 2014). Though smallholder farmers produce much of the food in Africa, they are also those most affected by food insecurity (Herrero et al., 2010). Improving food production, in terms of quantity and quality, is needed to improve food security.

Research results suggest that agricultural diversification towards integrated crop-livestock systems is most promising in many aspects of sustainability such as resilience to climatic and environmental extremes, food security and sustainable livelihoods (Waha et al., 2018). The synergies of livestock husbandry and crop production present a wide range of possibilities to increase productivity, resource efficiency, farmer income and food security while maintaining environmental services (Herrero et
al., 2010). However, whether adaptation towards diversification, intensification or specialisation is taking place, is feasible or is recommendable depends on the region and context (Chen et al., 2018). Scientific evidence with respect to the impacts of specialised and diversified farming systems on food security is still limited. Therefore, this study aims to assess the food security status, its determinants, and the coping strategies of farmer households in crop, livestock and mixed crop-livestock systems in southern Mali.

Methods and Study Site
A survey was conducted with 258 households from October to December 2012 in the communes of Sibirila and Garalo, located within the district of Bougouni in the Sikasso region of southern Mali. The region has a sub-humid climate, with an annual rainfall of between 1,000 and 1,200 mm. Interviews with sets of semi-structured questionnaires were used to collect socio-economic data on households, livestock holdings, cropping, household assets, inputs and outputs of animal and crop production for the previous 12 months, and coping strategies during the period of food shortage in August. Household heads and their wives were interviewed once during the harvest period between October and December in order to list, qualitatively describe and quantify food items prepared at home and consumed by household members during previous periods. These data were used to calculate the household dietary diversity score (HDDS), food consumption score (FCS), and a modified household food insecurity access scale (mHFIAS) as food security indicators.

HDDS was investigated according to the FAO guidelines for measuring household and individual dietary diversity (FAO 2011). FCS data were generated based on WFP (2008). mHFIAS was derived from a guideline proposed by Coates et al., (2007). Details of data collection methods for HDDS, FSC, mHFIAS and coping strategies are described by Traoré et al., (2018). Sampling of households was based on cattle and breed ownership as described by Traoré et al (2018). Households were re-categorized into three farming systems based on the share of farm income per year that was generated by livestock and crop production: 1) the livestock production system was characterized by farms with ≥ 90% of farm income derived from livestock production; 2) the mixed crop–livestock system was characterized by farms with ≥ 10% and ≤ 90% of farm income derived from crop or livestock; 3) the crop production system was characterized by farms with ≥ 90% of farm income derived from crops and with ≤ five tropical livestock units (TLU).

A linear mixed model was used to analyse the effects of household characteristics on food security using HDDS, FCS, mHFIAS and coping strategies as indicators. The considered effects on the food security indicators included farming systems (livestock, mixed and crop), number of crop species cultivated, number of livestock (i.e. TLU) and number of chickens raised by the household, dependency ratio, wealth index, milk production per farm in liters, by the household, cultivation of cotton, education of the household head, off-farm income and the random effects of communes (Sibirila, Garalo) and eight villages.

Results
Socioeconomic characteristics of households in farming systems
Age, education of the household head and dependency ratio were similar between the farming systems (p>0.1). All further socioeconomic characteristics differed significantly (p<0.1) between the farming systems (Table 1). The crop system had lowest values for livestock numbers, milk yield per farm, farm and household size and wealth index and the highest value for off-farm income. The livestock system showed highest values for milk yield, cattle number and TLU and lowest values for food crop species diversity and cotton cultivation.

Table 1: Means and standard deviation of socioeconomic characteristics of households by farming system

<table>
<thead>
<tr>
<th>Socioeconomic characteristics</th>
<th>Livestock (N=49)</th>
<th>Mixed (N=112)</th>
<th>Crop (N=97)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield per year per farm (L)</td>
<td>1907.1&lt;sup&gt;a&lt;/sup&gt; 1436.4</td>
<td>1149.8&lt;sup&gt;b&lt;/sup&gt; 1383.9</td>
<td>9.7&lt;sup&gt;c&lt;/sup&gt; 71.2</td>
</tr>
<tr>
<td>Education of household head</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt; 0.3</td>
<td>0.2&lt;sup&gt;a&lt;/sup&gt; 0.4</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt; 0.3</td>
</tr>
<tr>
<td>Household size (members)</td>
<td>14.0&lt;sup&gt;a&lt;/sup&gt; 9.0</td>
<td>16.0&lt;sup&gt;b&lt;/sup&gt; 7.4</td>
<td>10.7&lt;sup&gt;b&lt;/sup&gt; 4.2</td>
</tr>
<tr>
<td>Farm size (hectares)</td>
<td>8.4&lt;sup&gt;a&lt;/sup&gt; 10.5</td>
<td>13.1&lt;sup&gt;b&lt;/sup&gt; 7.5</td>
<td>7.7&lt;sup&gt;a&lt;/sup&gt; 5.3</td>
</tr>
<tr>
<td>Food crop species diversity (n)</td>
<td>2.8&lt;sup&gt;a&lt;/sup&gt; 1.4</td>
<td>3.7&lt;sup&gt;b&lt;/sup&gt; 1.4</td>
<td>3.5&lt;sup&gt;b&lt;/sup&gt; 1.5</td>
</tr>
<tr>
<td></td>
<td>1.3*</td>
<td>0.8</td>
<td>1.3*</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Wealth index</td>
<td>0.4*</td>
<td>1.2</td>
<td>0.4*</td>
</tr>
<tr>
<td>Off-farm income*</td>
<td>0.4*</td>
<td>0.5</td>
<td>0.4*</td>
</tr>
<tr>
<td>Cotton cultivation*</td>
<td>0.1*</td>
<td>0.4</td>
<td>0.7*</td>
</tr>
<tr>
<td>Chicken number</td>
<td>19.1*</td>
<td>17.7</td>
<td>22.6*</td>
</tr>
<tr>
<td>Cattle (actual number)</td>
<td>48.1*</td>
<td>36.7</td>
<td>31.7*</td>
</tr>
<tr>
<td>Tropical Livestock Units (TLU)</td>
<td>36.2*</td>
<td>26.9</td>
<td>24.8*</td>
</tr>
</tbody>
</table>

* Indicates dummy variables (yes = 1, no = 0); 1 Ratio of household members, who are aged 0–14 and above 65 years to the productive age group; 2 Based on number of motorcycles, phones, radios, ploughs, total livestock units and total revenue; a, b, c - means within a row with different superscripts differ significantly at P < 0.10.

**Food security in farming systems**

Figure 1 shows that the frequency of consumption of vegetables as well as that for high energy foods such as oils and fats, cereals and sweets were similar among households of the three farming systems. Largest differences in the frequency of consumption among systems was for milk. Moreover, the share of households that consumed milk was 90% for livestock, 65% for mixed and 30% for crop systems. Average daily milk consumption was 201 ml in livestock, 110 ml in mixed and 60 ml in crop systems. With respect to meat consumption, beef, mutton, goat meat and poultry meat were consumed less frequently in crop systems. Beef was consumed almost once per week in crop and less than twice per week in livestock systems. Dry fish was consumed in the majority of households in all systems about 5 times per week. However, the quantity of dried fish was very low (data not shown). Fresh fish was most frequently consumed in the mixed system (about once per week) and least frequently in the livestock system. Almost no eggs were consumed in none of the households of the different systems. The protein sources milk, meat and legumes were consumed least frequently in crop systems.

![Figure 1: Frequency of consumption of different food types in the past seven days by farming system.](image)

Table 2 shows that all food security indicators differed significantly between farming systems. Livestock systems had highest and crop systems lowest values for FCS and HDDS. Moreover, crop systems had highest values for food insecurity indicators.
Table 2: Least square means (LSMs) and standard errors (SE) of FCS, HDDS and mHFIAS and food shortage length by farming system

<table>
<thead>
<tr>
<th>Food security indicator</th>
<th>Livestock (N=49)</th>
<th>Mixed (N=112)</th>
<th>Crop (N=97)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCS</td>
<td>LSM SE</td>
<td>LSM SE</td>
<td>LSM SE</td>
</tr>
<tr>
<td></td>
<td>87.93a 2.5</td>
<td>76.29b 1.5</td>
<td>68.72c 1.8</td>
</tr>
<tr>
<td>HDDS</td>
<td>8.91a 0.3</td>
<td>8.15b 0.2</td>
<td>8.07b 0.2</td>
</tr>
<tr>
<td>mHFIAS for harvest period</td>
<td>0.66a 0.36</td>
<td>0.47a 0.27</td>
<td>1.97b 0.25</td>
</tr>
<tr>
<td>mHFIAS for lean period</td>
<td>0.90a 0.45</td>
<td>1.49b 0.29</td>
<td>4.27b 0.32</td>
</tr>
<tr>
<td>Food shortage length (months)</td>
<td>0.88a 0.14</td>
<td>0.74a 0.09</td>
<td>1.25b 0.11</td>
</tr>
</tbody>
</table>

Within rows, least square means with different superscripts differ significantly (p<0.10).

Table 3 shows determinants of HDDS and FCS. FCS was positively influenced by the number of crops cultivated, total farm milk production, off-farm income and number of chickens raised in the farm (p<0.1). HDDS was positively influenced by crop diversity, number of chickens and negatively associated with the number of family dependents. Cotton cultivation showed no significant effect on FCS or HDDS.

During the food shortage period of August, households from livestock and mixed systems were less affected and had significantly lower mHFIAS than those belonging to the crop system. The length of the food shortage period was higher in the crop system than in the livestock and mixed systems and was negatively associated to the number of TLU. For the crop system, 27% of households were suffering from severe food insecurity and 84% had food shortage for at least one month. Only 38% of households in the crop system were food secure whereas 73% of households in the livestock system were food secure. During the food shortage month selling livestock was the main coping strategy for households of the livestock and mixed system, while the households of the crop system had to buy food by borrowing cash. In general, the crop system showed the most deleterious coping strategies.

Table 3: Regression analysis of determinants of HDDS and FCS

<table>
<thead>
<tr>
<th>Agricultural system (ref=mixed)</th>
<th>HDDS Estimate</th>
<th>SE</th>
<th>P-value</th>
<th>FCS Estimate</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock system</td>
<td>0.75</td>
<td>0.27</td>
<td>0.0069</td>
<td>10.54</td>
<td>3.00</td>
<td>0.0005</td>
</tr>
<tr>
<td>Crop system</td>
<td>-0.09</td>
<td>0.25</td>
<td>0.1712</td>
<td>-7.85</td>
<td>2.60</td>
<td>0.0030</td>
</tr>
<tr>
<td>Food crop species diversity</td>
<td>0.39</td>
<td>0.07</td>
<td>&lt;.0001</td>
<td>2.25</td>
<td>0.70</td>
<td>0.0015</td>
</tr>
<tr>
<td>Chicken number</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0216</td>
<td>0.13</td>
<td>0.06</td>
<td>0.0167</td>
</tr>
<tr>
<td>Dependency ratio</td>
<td>-0.25</td>
<td>0.11</td>
<td>0.0241</td>
<td>&gt;0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk production</td>
<td>&gt;0.1</td>
<td></td>
<td>0.0034</td>
<td>0.0010</td>
<td></td>
<td>0.0004</td>
</tr>
<tr>
<td>Off-farm income</td>
<td>&gt;0.1</td>
<td></td>
<td>3.72</td>
<td>2.10</td>
<td></td>
<td>0.0774</td>
</tr>
</tbody>
</table>

Estimates are presented only for household characteristics found to satisfy a P<0.1 significance level.

Discussion
The farming system played a significant role in all investigated food security indicators. Households from the livestock and mixed systems performed better with respect to food access and food diversity, had lower household food insecurity, higher resilience to food shortages and had less deleterious coping strategies compared to households of the crop system, especially during the lean period. The quantity and quality of food produced influenced the quantity and quality of food consumed. The diversity of produced food crops was positively associated with the food diversity of the households. The high differences in FCS between systems were largely influenced by differences in milk consumption. Higher milk and chicken production improved food security. The study confirms that crop diversification and increasing livestock production (milk and chicken) could improve food security. Site-adapted strategies should be prioritized to improve production of and access to high quality food in crop systems. Further studies are needed to reveal FCS and HDDS during the food shortage period.
Acknowledgements
The financial support of the German Academic Exchange Service (DAAD) and the Foundation Fiat Panis is greatly acknowledged.

References


Why We Need a Ruminant Revolution: Combating Malnutrition and Metabolic Illnesses to Enable Sustainable Development

Ballerstedt, P.J.¹; Hannaway, D.B.²; Noakes, T.D.³

¹Forage Ambassador, Barenbrug USA; ²Professor and Forage Program Director, Oregon State University, USA; ³Adjunct Professor, Cape Peninsula University of Technology, Cape Town, South Africa

Key words: [malnutrition; diabetes; obesity; metabolic health; insulin resistance]

Abstract

Animal source foods (ASF) are essential for proper human development and function. Livestock in general, and ruminants in particular, are essential components of our sustainable global food systems. Of significant worldwide impact, diets with higher-than-recommended levels of ASF can correct the symptoms of metabolic illnesses, offering hope in arresting the current worldwide epidemic of diabetes and other metabolic diseases. Most dietary policies and recommendations are based on the ill-founded belief that plant-based, high-carbohydrate diets are “healthy.” High-quality scientific evidence does not support the belief that vegetarian diets are healthier than omnivorous or animal-based diets. A Therapeutic Carbohydrate Reduction (TCR) lifestyle approach has demonstrated its efficacy in reversing Insulin Resistance (IR) and the non-communicable diseases associated with or caused by it. True sustainability is a multifaceted topic of societal, economic, and ecological aspects. The enormous suffering and financial costs of chronic illness must be acknowledged. The production of high-quality animal protein and animal fat by ruminants from feed resources humans cannot directly utilize will be fundamental to feeding a growing population. This essential food production can preserve and enhance the diverse environments where it takes place. We need a revolution in our thinking of what constitutes a healthy diet, what causes chronic illness, the vital role that animal products play in the human diet, and the essential nature of ruminant animal agriculture in meeting humanity’s needs. This will mean overthrowing established policies and institutions and confronting vested belief systems. We’ll need an effort, analogous to the Green Revolution, to develop and deploy the knowledge and technology necessary to meet the needs of the mid-21st Century world.

Introduction

Based upon the highest quality scientific evidence available, we must more effectively communicate these objective realities: 1) Too much of humanity suffers from too little animal source foods (ASF) in their diet (Adesogan et al. 2019; Berg 2019); 2) There is insufficient evidence to recommend reducing ASF consumption, even in high-income countries (Carroll and Doherty 2019); 3) Dietary interventions based upon reducing processed carbohydrates and ensuring adequate ASF offer enormous promise in lower the global burden of non-communicable diseases (Bikman 2020); 4) Grasslands and ruminant animal agriculture are essential to sustainable foods systems and sustainable development globally. Given: The global epidemic of metabolic diseases; The failure of the global human nutrition leadership to acknowledge the weak scientific basis of their dietary guidance and their failure to reverse this epidemic; And their inability to incorporate the highest-quality scientific evidence available into their guidance and policies, we argue that those of us in grassland agriculture and ruminant animal agriculture must stop accepting their pronouncements, stop citing them in our research and challenge their legitimacy wherever possible.

Approach

Our paper is intended as a “call to action.” We hope to introduce this argument and provide sufficient references to permit further investigation, encourage individuals to improve their health, and initiate action by the International Grasslands Congress and its participating organizations and members.

Results

Malnutrition Today
Despite the advances made in agricultural productivity resulting from the so-called “Green Revolution,” approximately 800 million human beings are still calorically undernourished (World Hunger Education Service 2018), while 2.2 billion are overweight or obese (Ng 2014). These observations might seem paradoxical to those not familiar with the current research on human nutrition and metabolic health. However, a viewpoint informed by this body of work understands that this condition is what should be expected from malnourished populations (Taubes 2007).

In 2012, the World Health Assembly (WHA) agreed on six global targets for improving maternal, infant and young child nutrition by 2025 (WHO 2012). In 2015, the Sustainable Development Goals established a global agenda for substantial improvement in nutrition by the year 2030, setting a specific objective of ending all forms of malnutrition by 2030, including achieving the 2025 targets and addressing the nutritional needs of adolescent girls, pregnant and lactating women, and older persons (FAO 2018).

It has been estimated that by 2050: The global population will reach 9.8 billion (UN 2017), 70% of which will live in urban areas (Bryce 2020); Food production must double (UN 2009); Demand for animal-sourced protein will increase by 66% (FAO 2017). Therefore, major gains in the efficiency of livestock systems are needed if these predictions and the 2030 goals of the Agenda for Sustainable Development are met (FAO 2017).

Animal source foods are essential for human development and health (Adesogan et al., 2019). Ruminant animal agriculture offers unique ecological advantages over other methods of ASF production (CAST 1975), but improvements in grassland management and ruminant animal agriculture are required if increased productivity with reduced environmental impacts are to be achieved (Capper and Bauman 2013; FAO 2017). Public health policy and advocacy by numerous interest groups (e.g., see Banta et al., 2018) has been decidedly anti-red meat, animal fat, and ruminant animal agriculture for almost half a century (Leroy and Hite 2020). Their arguments are based on health claims, environmental issues, and personal beliefs/feelings. While largely unsupported by high-quality scientific evidence, their efforts have influenced policy priorities and, therefore, the funding needed for the research and development efforts necessary to advance grassland agriculture.

**The Unsustainable Burden**

Non-communicable (or chronic) diseases (NCD) account for 71% of all deaths globally (WHO 2018). While the most dietary policy is informed by the belief that obesity is the *cause* or a *risk factor* for much of this burden, high-quality scientific evidence strongly suggests that insulin resistance and hyperinsulinemia are at least aggravating, if not causal factors (Crofts 2015; Bikman 2020).

Dietary policies and nutrition education have been primarily guided by the results of Nutritional Epidemiology of Chronic Disease (NECD) surveys and cohort studies (Hite 2018). Eighty per cent of the findings of NECD have been disproven by subsequent clinical trials (Young and Karr 2018). Despite the investment of billions of United States (US) dollars since Keys and his colleagues proposed (and then promoted) the hypothesis that naturally-occurring saturated fatty acids in the diet caused heart disease (Key et al., 1955), “[t]he evidence implicating natural dietary fats in heart disease has evaporated over the years” (Taubes 2020). Despite this failure, dietary guidance remains to eat less red meat and low-fat dairy products, the primary products of grassland agriculture.

IR is an epidemic that few have heard of. Yet, half of all adults in the US and roughly one in three Americans are known to have it (Menke et al., 2015). Almost 90% of US adults have one or more conditions of metabolic ill-health (Araújo et al., 2019). Contrary to the “plagues of prosperity” narrative, low-income countries have passed high-income countries regarding the total number of people with the condition (Roglic et al., 2016). Eighty per cent of all individuals with IR now live in low- and middle-income countries and, as in America, half of all adults in China and India are insulin resistant (Roglic et al., 2016). The number of people with diabetes is predicted to increase by 150% in the next 25 years (WHO and IDF 2004).

The overwhelming majority of people with IR don’t know they have it and have never heard of it (Bikman 2020). Educational efforts have been and will continue to be hampered by the conventional wisdom that Type 2 Diabetes (IR) is *caused* by obesity, sedentary behaviour, and an unhealthy diet (which is defined as one containing too many animal source foods, especially red meat). All of these are incorrect (Taubes 2007; Bikman 2020).

The social, economic, and environmental burdens of this epidemic of malnutrition are unsustainable

**An Effective Approach**

The historical origins of carbohydrate restriction (CR) date back to 1825 when Jean Anthelme
Brillat-Savarin published *The Physiology of Taste* (Taubes 2007). In 1864, William Banting’s *Letter on Corpulence* reached a remarkably wide audience for its time. In the early 20th century, interest in therapeutic carbohydrate restriction (TCR) resurfaced in the context of two chronic diseases: diabetes mellitus and epilepsy. Interest waned with exogenous insulin and anti-seizure medications (Westman et al., 2006; Freeman 2013). Several authors revived the carbohydrate restriction for weight loss in the 1960s and 1970s, followed by another wave in the 1990s (Taubes 2007). This low-carbohydrate (LC), weight-loss diet books far outsell those produced by the American Heart Association and the Dietary Guidelines for Americans (which promote low-fat, high carbohydrate diets (Blackburn et al., 2001), suggesting that the results produced by the former surpass those of the latter (Taubes 2020). The portrayal of these diets in the media as “fad diets” for “quick weight loss” obscures their utility in clinical settings as interventions for specific conditions (Society of Metabolic Health Practitioners 2020). Despite this coverage and the opposition by various medical/special interest groups, there has been a revival of interest in LC diets as clinical interventions for specific conditions. Most notably for this discussion, varying degrees of CR are among the most effective dietary interventions for treating type 2 diabetes, surpassing the effects produced by medications and producing drug-free remission. A recent Western Australian government report states that remission, rather than just management, should be the goal of interventions for type 2 diabetes. An LC diet should be one of the options formally offered to patients with this diagnosis (Freeman et al., 2019). A 2019 consensus statement from the American Diabetes Association indicates that LC diets should be included as one of the nutrition therapy options offered to people with type 2 diabetes. The report also notes that “Reducing overall carbohydrate intake for individuals with diabetes has demonstrated the most evidence for improving glycemia and may be applied in a variety of eating patterns that meet individual needs and preferences” (Evert et al., 2019). Dr. David Unwin, a U.K. general practitioner, has demonstrated to the National Health Service (NHS) how a low-carbohydrate diet can save money by offering patients alternative medications. In recognition of his work, Dr. Unwin has been named a Royal College of General Practitioners Clinical Expert in Diabetes and NHS Innovator of the Year 2016.

**Grasslands’ Role**

Members of the International Grasslands Congress are aware of the critical role that grasslands play in our global ecosystems, the ecosystem services provided by grassland agriculture, and livestock’s role in sustainable development. Unfortunately, in addition to all the work being done in grassland and rangeland sciences, we must now become familiar with the scientific literature regarding the role of grassland agriculture’s primary products (red meat and full-fat dairy) play in human nutrition and health. There are a variety of dietary approaches that qualify as LC and TCR, but they typically include a higher amount of ASF (including red meat and full-fat dairy products) than is commonly recommended.

**Call to Action**

Humanity must improve the productivity and efficiency of our grassland agricultural systems to sustainably contribute to the higher quality and greater quantity of food to the global food supply if the sustainable development goals are to be met. This will require: A more inclusive understanding of malnourishment; An unbiased appreciation of the role of ASF in human nutrition and health; The role of IR in NCD; And a greater appreciation of our global ruminant agriculture systems and the grasslands they (and all of us) depend upon. Given the failure of the traditional experts on human health and nutrition, those in grassland agriculture must educate themselves on these subjects. We must stop giving their pronouncements credence without rigorous challenges. Their unfounded pronouncements have contaminated our scientific literature, and their ill-founded policies affect research and development funding priorities.

On the personal level, the membership of this body needs to understand how to feed themselves. The odds are that a significant number of members currently have IR and its related conditions and could benefit from an LC lifestyle intervention. People who have experienced this health journey often become advocates.

The 2023 International Grasslands Congress theme is “Grasslands for Soil, Animal and Human Health.” We hope that between now and then, this organization and its members respond to this call, improve their health when appropriate, and promote our enterprises as the foundation for alleviating the global scourge of IR and its associated diseases.
References


CAST. 1975. Ruminants as Food Producers: Now and In the Future. Council for Agricultural Science and Technology. Special Publication No. 4


[Books]

[Websites]
Analysis of Actors and Activities at Dagoretti Livestock Market in Nairobi City, Kenya

Wafula, W.M.; Wasonga, O.V
Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya.
*Corresponding author’s email: wamagero@gmail.com

Key words: actors, livestock trade, market, pastoralists

Abstract
Livestock production is the main economic activity in the vast drylands of Kenya, with more than 60% of livestock population being reared by pastoralists in the arid and semi-arid areas of the country. The sector employs 90% of populations living in the ASALs of Kenya. Most of the beef animals from the pastoral system end up in the urban areas where some of the largest terminal markets are located. Nairobi being the Capital City of Kenya hosts some of the biggest livestock markets in the country. Whereas livestock trade in these markets is known to contribute to household incomes and the County revenue, there is hardly any documentation of the business activities, actors and the challenges to guide interventions by County government. This study analyzed the types and sources animals for trade, actors in livestock trade, their roles, associated business opportunities and challenges faced in Dagoretti Market located in Nairobi City County. The results show that Dagoretti livestock Market is dominated by pastoralists who trade in cattle, sheep and goats with 56.8%, 34.1% and 9.1% respectively. These animals are mainly sourced from Kenyan rangelands, Uganda and Tanzania. The main market actors consist of sellers of live animals, meat, blood, hides and skins, horns, livestock-transporters, butchers, branders, brokers, butchers, health officers, security guards and revenue officers. This market has attracted a myriad of income opportunities such as sell of sawdust, sand, manure, forage, food vendors, cleaners, landlords, loaders/off-loaders, trekkers and herders of unsold animals. This study reveals that livestock trade contributes immensely to household incomes, employment-creation and government revenue. However, tax and fee barriers, theft and poor infrastructures are the key threats to this business. There is therefore need for County governments to consider resource allocation and policy formation on livestock trade; to address challenges faced, improve business efficiency, opportunities and profitability of market actors: to spur the nation’s economy.

Introduction
Livestock trade is an important livelihood activity and source of income to over 200 million pastoralist households globally (African Union 2015; Dong et al., 2016; Tully and Shapiro 2014). It contributes significantly to the world’s agricultural Gross Domestic Product (GDP) that is 40% globally, 35% in Africa, 40% in East Africa and 42% in Kenya (FAO 2009; GoK 2019; Nyariki 2017). In Kenya, pastoral production dominates livestock markets supplying over 70% of the country’s livestock, and is practiced in arid and semi-arid areas (ASALs), which comprise approximately 89% of the nation’s landmass (FAO 2018; GoK 2012). Livestock industry operates at several nodes through several processes and chain actors who link producers to the final market mainly for consumption as cattle, sheep and goat-meat (Alarcon et al., 2017; Mahmoud 2010)mutton and goat products is expected to double by 2030. The study aimed to map the Nairobi beef, sheep and goat systems structure and flows to identify deficiencies and vulnerabilities to shocks. Cross-sectional data were collected through focus group discussions and interviews with people operating in Nairobi ruminant livestock and meat markets and in the large processing companies. Qualitative and quantitative data were obtained about the type of people, animals, products and value adding activities in the chains, and their structural, spatial
and temporal interactions. Mapping analysis was done in three different dimensions: people and product profiling (interactions of people and products).

Historically, livestock trade among pastoralists in Kenya dates back in over 200 years ago, where they engaged in barter trade to exchanged crops with an agreed equivalent number of animals (Waller 2012). Traditionally, keep pastoral communities indigenous livestock species comprising cattle, sheep, goats, camels and donkeys (Omollo 2017) as well as to diversify their household incomes from the sale of the produced hay and grass seed. However, there is limited information to guide targeting and prioritization of options for up-scaling fodder production for enhanced pastoral and agro-pastoral livelihoods. This study was conducted in Kajiado and Makueni Counties of southern Kenya to characterize hay and grass seed value chain, determine profitability of hay and grass seed and efficiency of their marketing channels; and assess factors that determine households’ participation in fodder production. Data was collected through household interviews using semi-structured questionnaire, key informant interviews and focus group discussions. Range pasture reseeding was found to be the most common production technology, practiced by 48% of the sampled producers. Analysis of the fodder value chain showed that key players at the production level were individual farmers and social groups who provided own labour for ploughing and sourced for own grass seeds. The Kenya Agricultural and Livestock Research Organization played key roles throughout the value chain, including provision of startup seeds, training producers on agronomic practices, and linking producers to the markets. Traders were found to dominate fodder markets; they bought grass seeds from the producers at low prices and sold mainly to international organizations. The main buyers of grass seeds in the study areas were United Nations Food and Agriculture Organization (FAO). However, the arrival and settlement of British colonial government in Kenya in 1880s marked the shift from the traditional livestock trading system. During this era, the colonial government came up with new regulatory frameworks in livestock trade, such as introduction of monetary system as a recognized form of exchange and requirement for destocking among pastoralists through trade to attain ecosystem’s carrying capacity (Guyo 2017). In 1902, when the European settlers introduced exotic livestock species in the country’s highland regions and formation of the Kenya Meat Commission in 1950 (GoK 2019). In addition, the agricultural intensification strategy of 1954 led to the establishment of Livestock Marketing Division as well as permitting Africans to keep and trade in exotic livestock breeds (Swynnerton 1954). Since then, the country’s livestock trade industry has continued to advance through development of policies supporting local and export livestock trade.

Livestock markets in Kenya are structured into primary, secondary or tertiary markets, whereby; primary markets usually have few buyers, low market prices and in rural areas; secondary ones are located in urban areas with high market demand, livestock volume of traded animals and high prices (Farah 2011); whereas tertiary markets comprise the cross-border and export trade to other countries (Arero 2018; Tessema et al., 2019). The livestock survey report of 2019 shows that the country’s ruminant livestock comprise 15.8 million cattle (consisting 82% indigenous, and 18% exotic breeds), 28 million goats, 19.3 million sheep, 4.6 million camels, and 1.2 million donkeys (KNBS 2020). Livestock sector has attracted several research funding to boost food security, employments and poverty alleviation in the country (Mahmoud 2010; Roba 2018).

Currently, pastoral livestock trade is a fundamental tool in attaining economic development goals both locally and globally (African Union 2015; GoK 2017, 2019; United Nations 2019). In Kenya, studies have shown that the demand for livestock meat, milk and other livestock-products is expected to increase, with peak cases in the largest cities; Nairobi and Mombasa City (FAO 2018; Robinson and Pozzi 2011). This demand has been occasioned by rapid urbanization, increase in human population, income levels and change in consumption patterns in favor of animal-protein (Oyugi et al., 2017). It is projected also that by the year 2030, the demand for beef, mutton and goat-meat will have risen by a double proportion, hence increasing pressure on pastoral production as the major supplier of animals for trade (Alarcon et al., 2017). This demand is expected to double by 2030. The study aimed to map the Nairobi beef, sheep and goat products is expected to double by 2030. The study aimed to map the Nairobi beef, sheep and goat products is expected to double by 2030.
Despite its immense contribution in livestock trade, pastoralism still experiences a myriad of challenges that continue to drag behind the perceived merits. Key of these challenges include; poor infrastructure, transport and communication systems, poor pricing, lack of financing by the government and financial institutions, frequent and prolonged droughts diminishing grazing resources (Iruata et al., 2015; Kandachar and Halme, 2017; Nyariki, 2017). Although several studies have been conducted in promotion of livestock revenue through trade, the general contribution of individual market actors, activities and opportunities arising from livestock trade in urban areas is still overlooked. Understanding such information is necessary in informing policy interventions and practices that will enhance efficiency and improved livestock trade, for increased returns to various actors and the general economy.

Materials and Methods

Study Area

This study was conducted in Dagoretti livestock market located on the border of Nairobi City County and Kiambu County, Kenya. Geographically, the market is situated at latitude 01°17’ South, and longitude 036°41’ East. It is at an altitude of approximately 1,900 meters above sea level and experiences an average rainfall of 1000 mm, a mean annual temperature of 19°C and relatively higher humidity (above 80%) in the morning, and lower (below 40%) in the afternoon (GoK 2014; Makokha and Shisanya 2010). Dagoretti market, also known as Ndonyo (which means ‘the market-place’ in Kikuyu language) is the major livestock market that serves residents in Nairobi City, Kiambu and Kajiado Counties. It was selected as the largest livestock market supplying ruminant meat and other livestock-products in Nairobi City and its neighboring towns on daily basis. Established in 1950, the market occupies approximately 6.8-hectare land along the Nairobi-Naivasha railway line. This railway line was formally used in transportation of people and livestock for trade from white-settler farms in Rift Valley region to City of Nairobi mainly sale and slaughter. Until today, it is the main terminal market of livestock from the pastoral areas in Kenya as well as the neighboring countries.

Data

Data for this study was collected using semi-structured key informant interviews (KIIs) and Focus group discussions (FGDs). Data collected entailed the market history, market actors and their roles, type and source of animals sold, and their selling price. A total of 41 KIIs, and 3 FGDs were conducted comprising between 6 to 8 market actors as participants (having at least 2 youth, 2 men and 2 women), to supplement information from obtained from the key informants.

Results and Discussions

The study reveals that Dagoretti urban livestock market is a major trading ground mainly for cattle, goats and sheep of pastoral livestock keepers from the Kenyan rangelands. In addition, livestock traders (pastoralists) also source animals for trade in Uganda and Tanzania to complement the nation’s livestock and livestock-product high demand. The livestock traders at the market were divided into two; small ruminant traders (sheep and goats) and large ruminant traders (cattle alone). The nature of animals traded are as reason of high livestock meat demand in urban and peri-urban areas, Nairobi being the peak market location (Oyugi et al., 2017). The findings also show that market brokers or intermediaries were the largest in number, followed by livestock traders and food vendors; as the dominant market players at 43.5%, 18.6% and 18.6% respectively.

The findings show that the animals traded at market consisted 99% indigenous and 1% exotic; consisting cattle (East African zebu, Boran, Ankole, Sahiwal, crosses of cattle and Jersey cattle), Goats (Galla, Small East African goat and crosses of goats), whereas sheep (Dorper, Red Maasai sheep, Somali Black-head and crosses of sheep). The findings reveal that the traded animals come from pastoral territories of the nation 43.02% in southern Kenya, 21.68%, northern Kenya, 17.22% eastern Kenya, 7.32% Rift Valley and western region; while 1.42% in central Kenya. From the neighboring nations, 7.1% of cattle originated from Uganda, mainly Ankole breed, while 2.23% from Tanzania.

Table 3: Volumes of animals sold Monthly

<table>
<thead>
<tr>
<th>Livestock species</th>
<th>Average No. of livestock sold monthly</th>
<th>Average market price of the animal (USD)</th>
<th>Monthly Sales in (USD)</th>
<th>Percent Totals sold monthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>15,655</td>
<td>400</td>
<td>6,262,000</td>
<td>63.5%</td>
</tr>
<tr>
<td>Goats</td>
<td>1,927</td>
<td>65</td>
<td>125,255</td>
<td>7.8%</td>
</tr>
<tr>
<td>Sheep</td>
<td>7,057</td>
<td>60</td>
<td>423,420</td>
<td>28.7%</td>
</tr>
<tr>
<td>Totals</td>
<td>24,639</td>
<td>525</td>
<td>6,810,675</td>
<td>100%</td>
</tr>
</tbody>
</table>
Overall, livestock trade in the City market offered a range of informal employments to livestock traders, market middlemen, sellers of meat, livestock forages, manure, sand, sawdust, skin and horn dealers, track drivers, rental house owners, herders of unsold animals, food vendors, cleaners and security officers.

Conclusion and Recommendations

Dagoretti market is an important center for livestock trading in Nairobi City, and a source of income to market actors in various the market value-chain and value-additions. It is also a key source of the county and national government’s revenue through taxation. However, it is faced with a number of challenges including poor financing, poor infrastructure, multiple taxations at both inter-country and cross border during livestock transportation to the market. There is need for policy measures to promote livestock trade through infrastructural development, harmonization of livestock tax system for a one-stop taxation and financing of the livestock trade sector to enhance efficiency, and profitability to various market actors for economic development. Further research is required on livestock value chains in urban markets, costs and revenues in livestock trade, and willingness of market actors to pay for improved livestock trade.

References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forages and Environment Improvement
Nutrient return from plant litter and cattle excretion grazing on N-fertilized grass or grass-legume pastures in North Florida


1North Florida Research and Education Center, University of Florida, Marianna, FL, 32446; 2USDA-ARS Pasture Systems and Watershed Management Research Unit; 3Agronomy Department, University of Florida, Gainesville, FL.32611; 4Range Cattle Research and Education Center, Univ. of Florida, Ona, FL, 33865.

Key words: Legumes, grazing, nutrient cycling, ecosystem services.

Abstract
Nutrient recycling via plant litter and livestock excreta is an important ecosystem service provided by grasslands. This study determined nutrient return via these pathways in three grazing systems. The experiment was conducted from May to October (2016 and 2017) and treatments were: 1) Nitrogen fertilized bahiagrass (Paspalum notatum Flügge) pastures (112 kg N ha\(^{-1}\)) during the warm-season, overseeded with a mixture (56 kg ha\(^{-1}\) of each) of ‘FL 401’ cereal rye (Secale cereale, L.) and ‘RAM’ oat (Avena sativa, L.) during the cool-season (BGN); 2) Ecoturf Rhizoma peanut (Arachis glabrata Benth.) bahiagrass pastures during the warm-season, overseeded with similar rye/oat mixture fertilized with 34 kg N ha\(^{-1}\) plus a mixture of clovers (Trifolium incarnatum L., T. pretense L., and T. nigrescens L.) during the cool-season (BGRP); 3) unfertilized bahiagrass pastures during the warm-season, overseeded with similar rye/oat grass/clover mixture + 34 kg N ha\(^{-1}\) during the cool-season (BG). Litter mass was evaluated every 5wk. Litter decomposition was evaluated with incubation periods of 0, 2, 4, 8, 16, 32, 64, 128, and 256 days. Urine and fecal samples were collected for N concentration analysis. There was a net return of 47 kg N ha\(^{-1}\) season\(^{-1}\) via litter in all three systems without differing among them. In addition, litter decomposition rates were not different in the three systems. Conversely, N returned via excreta (urine and feces) was greater (63, 27, and 51 kg N ha\(^{-1}\) season\(^{-1}\)) than that returned via litter (58.6, 41.6, and 41.2 kg ha\(^{-1}\) season\(^{-1}\)). When assessing the proportions of N returning to the system via litter or excreta, no differences were observed among treatments, and on average 65.1 % of the N returned via excreta vs. 34.9 % returning via litter. The introduction of legumes could reduce the inputs from N fertilizers in grazing systems and keep the productivity similar because of more efficient N cycling.

Introduction
Nutrient cycling is an important supporting ecosystem service in grasslands and may possibly be affected by the type of forages, as well as management aspects such a stocking rate and N fertilizer application. Different grazing strategies can affect the size of nutrient pools such as C, N, P, and S in the ecosystem (Piñeiro et al., 2009). One of the most limiting nutrients in grasslands is N, and forage legumes might provide an alternative source of N, given their ability for biological N\(_2\) fixation (BNF), providing greater nutritive value for cattle, when compared with C4 grasses (Muir et al., 2011). Through the southeastern United States, bahiagrass (Paspalum notatum) is among the most widely perennial planted pastures, providing sufficient forage for beef cattle from spring to early autumn (Chambliss and Sollenberger, 1991). Bahiagrass is relatively more capable of tolerating heavy, continuous stocking, which often results in stand loss in other forage species (Sollenberger et al., 1988). Properly managing bahiagrass pastures, which includes adjusting the stocking rate according to the herbage mass and appropriate fertilizer application, increases the efficiency of nutrient cycling with little potential for negative impact on the environment (Sigua & Hubbard, 2010). Furthermore, integrating forage legumes into grazing systems provides alternatives to reduce dependency on commercial N fertilizer and to enhance nutrient cycling in grasslands. Rhizoma peanut (Arachis glabrata) is a warm-season perennial legume that is well adapted to Florida and the US Gulf Coast region.
Planting rhizoma peanut in strips into existing warm-season grass pastures has been advocated as an alternative method for its incorporation (Castillo, et al., 2013). The two major pathways of nutrient return in grazing systems are litter and excreta (Dubeux, et al., 2014). Plant litter is generally defined as the above-and belowground plant residues that undergoes partial decomposition and transformation by physical, chemical, or biological processes (Cotrufo et al., 2015). Establishing grass-legume mixtures is a practical way to increase plant litter quality, thus enhancing nutrient cycling and nutrient turnover during litter mineralization (Dubeux et al., 2007).

The overall objective of this study was to estimate the N returns via plant litter and excreta in three grazing systems. We hypothesized that inclusion of legumes will result in more efficient N cycling than in the N-fertilized system.

Materials and Methods

The grazing experiment was conducted at the University of Florida, North Florida Research and Education Center (NFREC) located in Marianna, FL (30°52'N, 85°11'W, 35 m a.s.l.). The perennial pastures were planted in 2014. Treatments consisted of three year-round forage systems. The first system (BGN) included N-fertilized (112 kg N ha\(^{-1}\) yr\(^{-1}\)) ‘Argentine’ bahiagrass pastures during the warm-season, overseeded with a mixture (56 kg ha\(^{-1}\) of each) of ‘FL 401’ cereal rye and ‘RAM’ oat during the cool-season with a second application of 112 kg N ha\(^{-1}\) yr\(^{-1}\). Total annual fertilization for this treatment was 224 kg N ha\(^{-1}\) yr\(^{-1}\). System 2 (BGRP) included ‘ecoturf’ rhizoma peanut and bahiagrass pastures during the warm-season, overseeded with a similar rye-oat mixture, fertilized with 34 kg N ha\(^{-1}\) plus a mixture of clovers (16.8 kg ha\(^{-1}\) of ‘Dixie’ crimson, 6.7 kg ha\(^{-1}\) of ‘Southern Belle’ red, and 3.4 kg ha\(^{-1}\) of ‘ball’ clover) during the cool season. System 3 (BG) included unfertilized bahiagrass pastures during the warm-season, overseeded with a similar rye-oat and clovers mixture than system 2, fertilized with 34 kg N ha\(^{-1}\) during the cool season. Pastures were continuously stocked with variable stocking rate. Two tester Angus crossbreed steers (Bos sp.) remained on each pasture throughout the season. Cattle of similar age, weight, and breed were allocated as needed to maintain similar herbage allowance (HA) among treatments, which was assessed every 14 d according to the methodology described by Sollenberger et al., (2005). Water, shade, and minerals were provided. Fecal and Urine samples were collected for posterior analysis of N concentration through the Dumas dry combustion method, using a Vario Micro Cube (Elementar, Hanau, Germany), after samples were ball milled using a Mixer Mill MM400 (Retsch, Haan, Germany) at 25 Hz for 9 min. Treatments were replicated three times in a randomized complete block design, and each pasture was considered the experimental unit. Litter was collected and incubated within each treatment having two replicated sampling units for each time point, and each pasture remaining as the experimental unit. The incubation times were 4, 8, 16, 32, 64, 128, and 256 d. The litter bags were placed on the ground, in sets of six (one for each incubation time), at two different locations within each pasture, and covered with existing litter from the given experimental unit. After each incubation period, all bags were dried in a forced-air oven at 55°C to a constant weight and N was analyzed through the Dumas dry combustion method. The Mixed Procedure of SAS (SAS Inst., Cary, NC) was used, and the model included the fixed effects of treatment, block and year were considered random effects.

Results

Herbage allowance during the warm season of 2016 and 2017 was 1.17, 1.16 and 1.16 kg DM kg LW\(^{-1}\) in BGN, BGRP, and BG, respectively (Figure 1). The stocking rate was least in the BGRP system (Figure 1) when compared with the other two systems (P < 0.01).

![Figure 1: Herbage allowance and stocking rate during the warm season of 2016 and 2017, in three grazing systems.](image-url)

BGN = bahiagrass with N fertilizer; BGRP = bahiagrass and rhizoma peanut; BG = bahiagrass.

\(a, b, c\) Means differ, \(P \leq 0.05\).
27, and 51 kg N ha\(^{-1}\) season\(^{-1}\) in BGN, BGRP and BG, respectively. The proportion of N that return to the system via excreta or litter did not differ among treatments (\(P \geq 0.05\)). The percentage of N returned via excreta on average was 65.1 % and via litter was 34.9 %.

**Figure 2:** Proportion of N return via excreta and litter during the warm season of 2016 and 2017, in three grazing systems

BGN = bahiagrass with N fertilizer; BGRP = bahiagrass and rhizoma peanut; BG = bahiagrass.

**Discussion**

The stocking rate was greater in the two systems with bahiagrass, despite the difference in N fertilization. Stocking rate in the rhizoma peanut was lower during the summer, affecting the annual average. The strip-planting approach used to establish the rhizoma peanut provided opportunity for selection, however, it resulted in overgrazing of the rhizoma peanut strips, reducing its productivity. This finding highlights the importance of forage legumes providing N to the grazing system and replacing inorganic N fertilizer. In grazing systems, one of the major N exchange pathways occur when ruminants graze legumes. The consumed N is transformed, assimilated, and the majority of it returns to the soil via urine and feces (Dubeux, *et al.*, 2007). Animal excreta return nutrient to the soil ranges from 70 to 90% of the total intake (Williams & Haynes, 1990). The proportion of N returning via dung and urine in this study was 65% and the amount of N that return in the grazing system can be significant and often concentrated in certain areas. However, the entry of nutrients is not uniform through the pasture, due to animal behavior and the partitioning of nutrients between feces and urine (Afzal & Adams, 1992). Management strategies such as rotational stocking with short grazing periods are alternatives for a better distribution of the nutrients through the pasture (Sollenberger *et al.*, 2002). The BG systems receiving 34 kg N ha\(^{-1}\) yr\(^{-1}\) recycled 80% of the N recycled in the grass system receiving 224 kg N ha\(^{-1}\) yr\(^{-1}\), indicating the potential of forage legumes to add N to grasslands. This also highlights the N losses from N fertilization, that result in lesser amount of N recycled to the pasture. Despite of greater N-fertilizer additions, there was no significant difference in N-returns via plant litter across the three systems. This is indicative of the importance of forage legumes for nutrient cycling in grazing systems (Dubeux *et al.*, 2007). Overall, approximately 2/3 of the N returned via excreta and 1/3 returned via litter. Nitrogen from excreta is more readily available, however, it is more prone to losses and unevenly distributed. Nitrogen from litter is more evenly distributed and decays slowly along the growing season, reducing N losses. Integration of forage legumes into livestock systems result in better quality litter and greater efficiency of N cycling, if compared with inorganic fertilizer (Jaramillo, 2020). In the current study, animal performance was similar for the N-fertilized grass system (224 kg N ha\(^{-1}\) yr\(^{-1}\)) compared with the grass-legume system using rhizoma peanut and fertilized with only 34 kg N ha\(^{-1}\) yr\(^{-1}\). On average, the estimated amount of N recycled in the grass-legume system using rhizoma peanut and fertilized with only 34 kg N ha\(^{-1}\) yr\(^{-1}\), that was similar to 234 kg N ha\(^{-1}\) yr\(^{-1}\) of N fertilizer. Therefore, on average each 1 kg of N recycled in the grass-legume system was equivalent to approximately 2 kg of N fertilizer (Dubeux *et al.*, 2020). In conclusion the N return via excreta and litter was similar in the three systems indicating that the introduction of legumes could reduce the inputs of N inorganic fertilizers in grazing systems.

**Acknowledgements**

Thanks to the support by USDA NIFA grant no. 2016-67019-24990 from the USDA National Institute of Food and Agriculture. We also would like to thank the collaboration of NFREC employees, interns and students for their help conducting this project.
References


The morphological, crude protein and in-vitro dry matter degradability characterisation of nine native grass species for veld restoration in semi-arid environment

Msiza, NH; Ravhuhali, KE; Mokoboki, HK; Sydney Mavengahama.

1Department of Animal Science, School of Agricultural Sciences, Faculty of Natural and Agricultural Sciences, North West University, Mmabatho 2735, South Africa
1Department of Crop Science, School of Agricultural Sciences, Faculty of Natural and Agricultural Sciences, North West University, Mmabatho 2735, South Africa
2Food Security and Safety Niche Area, School of Agricultural Sciences, Faculty of Natural and Agricultural Sciences, North West University, Mmabatho 2735, South Africa

Key words: [Semi-arid; rangeland; restoration; phenology; nutrition]

Abstract
Pasture production is dependent on results from favourable conditions that allow for stimulation of tillers, and the absence thereof does not promote the development of tillers. Therefore, the study sought to investigate the comparative characterisation of the morphology, crude protein and in-vitro dry matter degradability (DMD) of nine native grass species (Antheonpha pubescens, Cenchrus ciliaris, Chloris gayana, Dactylis glomerata, Digitaria eriantha, Eragrostis curvula, Festuca arundinacea, Panicum maximum & Themeda triandra), subjected under controlled conditions. Plants were assessed for germination percentage, chlorophyll, leaves and tillers, crude protein and in-vitro dry matter degradability (DMD). Data on these parameters were analysed using a one-way analysis of variance. Panicum maximum (log10 0.82) and T. triandra (log10 0.80) had a higher (P<0.05) an average number of leaves. Eragrostis curvula had the highest (P<0.05) chlorophyll content. Eragrostis curvula (61.57 g/kg DM) and D. glomerata (60.28 g/kg DM) grasses had higher (P<0.05) crude protein content. Festuca arundinacea (481.35 g/kg DM) had the highest (P<0.05) in vitro ruminal DMD36 values when compared to all other grasses. Festuca arundinacea (548.85 g/kg DM) had the highest (P<0.05) in vitro ruminal DMD48 values when compared to all other grasses. Chloris gayana, D. glomerata, D. eriantha, E. curvula, F. arundinacea, P. maximum and T. triandra had the highest average ranking values above 4.5 for most parameters. Due to their outperforming traits, these grasses serve as a dual purpose to the restoration of degraded rangelands.

Introduction
Natural pastures are distinctively the main source of diet for ruminants and remain a more accessible and cheaper animal feed. The availability of grasses in terms of quantity and quality determines the animal’s productivity. Ruminants are exposed to grazing rangelands that have further caused gradual damage to natural vegetation as they reach the threshold. Pasture production results from favourable conditions that allow for tillers’ stimulation, and the absence thereof does not promote the development of tillers (Benvenutti et al., 2006). Plant agronomic, morphological traits and nutritional value have directly influenced veld rehabilitation and animal production. The restoration through new plant pastures depends on raw materials (species), seed germination status, seedling growth, and type of grazing system (Ravhuhali et al., 2019). However, few studies have been published on establishing forage plants for veld restoration in semi-arid areas. This study sought to assess the morphology, crude protein and in-vitro DMD traits of prioritized (selected) grass species grown in semi-arid areas for veld restoration.

Materials and Methods
Study site: The study was conducted in a light-reflective greenhouse at Molelwane University Farm, 10 km from the North-West University, Mafikeng campus (25 85” 00” S, 25 63” 33” E). The location of the farm is semi-arid, with summer temperatures (22 - 34º C) and an above-average rainfall (300 – 700 mm) annually. The collection of soil samples was done from surrounding villages. Samples were mixed and analysed for chemical constituents. Eight of the grass species...
seeds studied in this experiment were outsourced from the Barenbrug seed company.

In contrast, the seeds of *T. triandra* species were hand-harvested around the Mafikeng area. Twenty seeds from each grass were randomly sown in separate plastic pots (30 cm diameter and 22 cm deep), and the same weight of soil was filled in the pots. A total of 81 pots (experimental unit) were used for sowing the grass species' seeds such that each species was replicated nine times. After germination, seedlings were further thinned out to 10 plants per pot. Plants were irrigated three times per week using a 750 mL container, and weeds were removed regularly from the pots.

Morphological traits measurements: Germination percentage, chlorophyll content index (CCI), number of leaves and tillers were assessed for each grass species. Germination percentage (%) was obtained and recorded five days after planting. The growth stage samples were in separate independent pots. The tallest tiller was used on each grass plant to measure the number of leaves per tiller.

Chlorophyll meter SPAD-502Plus measured chlorophyll (CCI) at each growth stage, and an average was recorded. The data was collected from October to December 2019 for grass morphology traits; grasses were further allowed to grow until March 2020 for tiller development.

Chemical analysis: The chemical constituents for crude protein (CP) and *in vitro* dry matter degradability were assessed at two growth stages (elongation and maturity), and an average was taken. Total crude protein content was determined following the standard macro Kjeldahl method (AOAC, 2005) and was converted to crude protein (CP) by multiplying the percentage N content by a factor of 6.25 and expressed in g/kg DM. The *in vitro* ruminal DMD of the samples were determined using the ANKOM Daisyll incubator set at 39 °C with four rotating jars according to the ANKOM Technology, method 3 for *in vitro* true digestibility. The samples were weighed into ANKOM F57 bags (0.45 – 0.5 g), heat-sealed, and placed in the digestion jars. Statistical analysis: Data on these parameters was analysed using a one-way analysis of variance (SAS, 2010)

Results

Results on germination percentage, the average number of leaves and tillers, chlorophyll content, crude protein, and *in vitro* DMD of grass species under greenhouse experiment are presented in Figures 1 (a, b) and 2 (a, b). The germination rate of the grass species in increasing order are as follows; *D. eriantha* – 23%; *P. maximum* – 38%; *D. glomerata* – 39%; *C. ciliaris* - 47%; *T. triandra* – 50%; *F. arundinacea* – 53%; *C. gayana* (53%); *A. pubescens* (56%) and *E. curvula* (72%). *Panicum maximum* (Mean ±Standard Error = 0.82 ±0.01) and *T. triandra* (0.80 ±0.01) had the highest (P<0.05) average number of leaves when compared to *F. arundinacea*, *C. gayana*, *D. glomerata*, *A. pubescens* and *E. curvula*. The average number of tillers were all similar (P>0.05). *Eragrostis curvula* (47.28 ±1.25) had the highest (P<0.05) chlorophyll content, while *F. arundinacea* (34.50 ±1.25) had the lowest chlorophyll content. *Eragrostis curvula* (61.57 ±0.72) and *D. glomerata* (60.28 ±0.72) grasses had higher (P<0.05) crude protein concentrations. *Cenchrus ciliaris* (32.67 ±0.72) and *T. triandra* (34.06 ±0.72) had the least (P<005) CP concentration. *Dactylis glomerata* (426.87 ±8.53) and *F. arundinacea* (440.51 ±8.53) had the highest (P<0.05) *in vitro* ruminal DMD24 values. *Festuca arundinacea* (481.35 ±6.84) had the highest (P<0.05) *in vitro* ruminal DMD36 values. *Festuca arundinacea* (548.85 ±7.88) had the highest (P<0.05) *in vitro* ruminal DMD48 values when compared to all other grasses. Table 1 summarises ranked grass species based on their germination %, chlorophyll, number of leaves and tillers, crude protein and *in vitro* DMD parameters according to their suitability and potential in restoring degraded rangelands using averages (1= unsuitable; 9= suitable). In the current study *D. glomerata*, *D. eriantha*, *F. arundinacea*, *P. maximum* and *T. triandra* had the highest average ranking values above 4.5 for most parameters.

![Figure 1: Effect of grass species on the number of leaves, number of tillers (a) and chlorophyll content (b) in nine selected grass species grown under controlled conditions. Standard error bar (SEB) leaves = 0.01](image-url)
Figure 2: Effect of species on crude protein (CP) (a) and in vitro DMD (DM in g/kg) (b) in nine selected grass species grown under controlled conditions. SEB crude protein = 0.72; SEB in vitro DMD12 = 5.02; DMD 72 = 8.32

Table 1: Veld restoration potential ranking of some nine selected grass species based on their morphological, nutritional and in vitro DMD parameters

<table>
<thead>
<tr>
<th>Grass species</th>
<th>GERM%</th>
<th>CCI</th>
<th>LN</th>
<th>TN</th>
<th>CP</th>
<th>DMD24</th>
<th>DMD36</th>
<th>DMD48</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. pubescens</td>
<td>8</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>C. ciliaris</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>C. gayana</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>D. glomerata</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>D. eriantha</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>E. curvula</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>6</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>F. arundinacea</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>P. maximum</td>
<td>2</td>
<td>8</td>
<td>9</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>T. triandra</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

GERM%: germination percentage; CCI: chlorophyll; LN: number of leaves; TN: number of tillers; CP: crude protein; DMD: dry matter degradability; AVG: average score
Discussion

Chlorophyll, number of leaves and number of tillers: The green colour in chlorophyll generally indicates the health status of grasses as a result of photosynthesis, which plays a vital role in the production potential of leaves (Sheikh et al., 2017). The efficiency of photosynthetic activity is magnified by the amount of chlorophyll in grasses, proving its capacity to absorb energy (Mishra et al., 2013). In this study, E. curvula recorded a higher chlorophyll concentration than other grasses (Figure 1b). Our E. curvula chlorophyll content results are higher than those of Biber (2007), which are Juncus roemerianus (11.98 CCI), Spartina alterniflora (29.97 CCI) and Rhizophora mangle (30.68 CCI). In our study, P. maximum (0.81± 0.03) and T. triandra (0.79± 0.03) had a higher average number of leaves, while all grasses in this study had the same average number of tillers. In the morphology of grasses, an increased number of tillers per shoot is a vital parameter because it yields better biomass quantity, decreases soil erosion, suppresses weeds, plant resistance in trampling, and prevents bush encroachment (Sun and Liddle, 1993). When a grass shoot produces many tillers, it clearly shows the efficient use of resources such as added organic matter enriching the soil post its life cycle (Montagner et al., 2012). Additionally, the number of tillers carries a highly crucial adaptability attribute since it measures the survival ability of grasses under intense defoliation periods, including the accessibility of reserves for photosynthesis (Laidlaw, 2005). Comparable to this study are findings of Mganga et al. (2010), who reported that the yield in tiller numbers differ with the species genetic make-up and growth habit. The genetic variation found in grass species is a common factor contributing to the differences in the production of leaves and tillers. Crude protein and in vitro dry matter degradability (DMD): crude protein is an important nutrient fraction in the diet of a ruminant due to its primary function of growth and production (Daba et al., 2019). E. curvula and D. glomerata had higher crude protein concentrations (Figure 2a). Eragrostis curvula from this study is higher than the one reported by Adejoro and Hassan (2017) (48.9 g/kg DM) and lower than Berhane et al. (2006) (93 g/kg DM). Thus, the crude protein concentration of these grasses was below the recommended minimum requirement of 85 g/kg DM/day on sheep and livestock. Information on the in vitro dry matter degradability (DMD) is vital in determining nutrient assimilation by ruminants (Birgit, 2017), including the digestibility and quality of substrates in the rumen (Ikhumioya et al., 2005). There was a variation among grasses at 24, 36 and 48 hours after incubation. Festuca arundinacea had a higher DMD36 (481.35 g/kg DM) and DMD48 (548.85 g/kg DM) value than all other grasses (Figure 2b). Both results were higher than that reported by Elizalde et al. (1999) (381 g/kg DM). Generally, in this study, D. glomerata, F. arundinacea, and P. maximum leaves had high degradability and equally high CP content. Several authors explain that high CP and low fibre content in animal diets cause an increase of rumen degradability (up to 600 g/kg), thus showing that a relationship exists between CP and fibre (Yuan et al., 2017, Ravhuhali et al., 2018, Ramantsi et al., 2020, Ravhuhali et al., 2020).

Conclusions

Chloris gayana, D. glomerata, D. eriantha, E. curvula, F. arundinacea, P. maximum and T. triandra species had a higher ranking based on their different morphological, nutritional (CP), and in vitro DMD traits assessed among these grasses. Therefore, these grasses serve a dual purpose due to their outperforming traits.

Acknowledgements

Sponsors: National Research Fund, Meat Industry Trust and North-West University Postgraduate bursary for financial support are therefore acknowledged.

References


Grass-legume mixtures for diversified and profitable forage production

Islam, M.A.; Ashilenje, D.

Department of Plant Sciences, University of Wyoming, Laramie, WY 82071, USA

Key words: profitability; gross margin; nutritive value

Abstract

Grass-legume mixtures can improve forage yields, nutritive value, and net economic benefits. A replicated experiment was conducted from 2013-2017 at the University of Wyoming Sheridan Research and Extension Center to determine forage yield, nutritive value, and gross margin for meadow bromegrass (*Bromus riparius* Rehm.), alfalfa (*Medicago sativa* L.), sainfoin (*Onobrychis viciifolia* Scop.), and birdsfoot trefoil (*Lotus corniculatus* L.) mixtures and monocultures. Treatments included 50-50% and 70-30% mixtures of meadow bromegrass with each legume and 50-25-25% mixture of meadow bromegrass with two legumes and 50-16.7-16.7-16.7% mixture of meadow bromegrass, alfalfa, sainfoin, and birdsfoot trefoil. Grass monocultures received 0, 50, and 100 pounds of nitrogen (N) per acre as urea. The study was established in 2013 and plots were harvested in mid-June, August, and October each year from 2014 to 2017. Harvested samples were used to estimate forage dry matter (DM) yield and nutritive value using the near infrared reflectance spectroscopy. Economic analysis was based on expenses involved in producing each crop according to different treatment and cumulative forage DM yields. Gross margin was calculated each year from the difference of cash inflow and variable operational cost. Total forage DM yield from mixtures was consistently higher than legume and grass monocultures. This was particularly evident in the 50-50% and 70-30% mixtures of meadow bromegrass with alfalfa and 70-30% mixture of meadow bromegrass with birdsfoot trefoil. Some of the grass-legume mixtures containing alfalfa and birdsfoot trefoil improved forage nutritive value to levels equivalent to good quality alfalfa. The 50-50% mixture of meadow bromegrass with alfalfa had the highest four-year total gross margin of $1497 per acre. There were no significant gains in profits for meadow bromegrass monoculture with or without N fertilizer. Overall, grass-legume mixtures, which include alfalfa and birdsfoot trefoil, have potential market value comparable to good quality, pure alfalfa.

Introduction

Hay production is a major contributor to US economy generating over $16 billion annually, 50% of which is from alfalfa (USDA NASS 2017). Productivity of alfalfa in the US in the last decade has been 3.4 tons per acre with a 0.004 ton per acre annual increase. In contrast, alfalfa hay price increased by $4 per ton each year. This indicates that there are opportunities to increasing production and income by diversifying forage crops. One way to realize this is through grass-legume mixtures. Studies indicate that grass-legume mixtures can improve forage yields, nutritive value, and net economic benefits (Dhakal 2005; Adjesiwor et al., 2017). Meadow bromegrass is one of the popular cool-season grasses found suitable for mixture. This species can grow upright and allows legumes to thrive in mixtures. Different combinations of meadow bromegrass and legumes including alfalfa, birdsfoot trefoil, and sainfoin can help alleviate challenges of producing monocrops that include costs of N fertilizers required to optimize yield, comparatively low nutritive value of grasses, and bloat disorder in livestock caused by alfalfa.

High forage nutritive value has been used as a benchmark for setting alfalfa and grass hay prices (USDA NASS 2018). Alfalfa hay with crude protein (CP) values of less than 16, 16-18, 18-20, 20-22, and greater than 22% is rated as utility, fair, good, premium, and supreme quality, respectively. While grass hay with CP concentrations less than 5, 5-9, 9-13, and greater than 13% is ranked as low, fair, good, and premium quality hay, respectively. Nutritive value of hay fed to cattle determines the net income from livestock farming. Livestock feed accounts for about 12% of the total farm operating cost (USDA NASS 2017). High quality hay enhances productivity of beef and dairy cattle. The objective of the study was to investigate whether diversified grass-legume
mixtures can increase not only productivity but also profitability of the forage farming systems.

Materials and Methods
The study was conducted during 2013 to 2017 at the University of Wyoming Sheridan Research and Extension Center (ShREC) in Wyoming to determine forage yield, nutritive value, and gross margin (GM) for meadow bromegrass, alfalfa, sainfoin, and birdsfoot trefoil mixtures and monocultures (Table 1). There were 50-50% and 70-30% mixtures of meadow bromegrass with each legume, 50-25-25% mixtures of meadow bromegrass with two legumes, and 50-16.7-16.7-16.7% mixture of meadow bromegrass with three legumes. Grass monocultures received 0, 50, and 100 pounds of N per acre. Seed rates and ratios were estimated based on pure live seed (PLS) basis (Cosgrove and Collins 2003) and recommended seeding rates. The recommended seeding rates based on PLS for meadow bromegrass, alfalfa, sainfoin and birdsfoot trefoil were 20, 20, 35, and 10 pounds per acre, respectively (Holzworth et al., 2003). Crops were harvested in mid-June, August, and October each year from 2014 to 2017. Harvested samples were used to estimate forage dry matter yield per acre and nutritive value using the near infrared reflectance spectroscopy. Economic analysis was based on expenses involved in producing each crop (Table 2) according to different treatment and cumulative forage dry matter yields. Each treatment was treated as an enterprise. Gross margins were calculated each year according to Equation GM=CI-VOC (Karellas et al., 2010), where CI is the cash inflow (US $) and VOC is the variable operational cost (US $).

Table 1: Description of grass-legume seed mass proportions and nitrogen (N) treatments

<table>
<thead>
<tr>
<th>Treatments†</th>
<th>Proportions of seeds by weight</th>
<th>N rate ib/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB-Alf (50-50)</td>
<td>50 50 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>70 30 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>50 50 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>70 30 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>50 50 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>70 30 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>50 50 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>70 30 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>50 50 0 0</td>
<td>0</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>70 30 0 0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Operation costs and prices for grass and legume hay at University of Wyoming Sheridan Research and extension center during the years 2014 to 2017

<table>
<thead>
<tr>
<th>Operation costs/hay prices</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed operation costs (US $ per year)</td>
<td>224.00 224.00 224.00 224.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel costs for crop monitoring (US $ per year)</td>
<td>2.00 2.00 2.00 2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead (land and labor charge, US $ per acre)†</td>
<td>61.52 61.52 61.52 61.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil tests (US $ per sample)</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable operation costs</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land preparation (US $ per acre)†</td>
<td>62.25 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicide (Orthosulfon, US $ per pound a.i.)†</td>
<td>2.00 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicide application (US $ per acre)†</td>
<td>7.00 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa seeds (US $ per pound)†</td>
<td>4.51 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridalhead wheat seeds (US $ per pound)†</td>
<td>0.25 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunflower seeds (US $ per pound)†</td>
<td>2.70 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meadow bromegrass seeds (US $ per pound)†</td>
<td>3.00 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting grass (US $ per acre)†</td>
<td>14.38 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting legumes (US $ per acre)†</td>
<td>15.38 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting mixtures (US $ per acre)†</td>
<td>17.44 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usea fertilizer (US $ per pound a.i.)†</td>
<td>0.85 0.85 0.85 0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer application (US $ per pound)†</td>
<td>6.24 6.24 6.24 6.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation (US $ per acre)†</td>
<td>72.87 72.87 72.87 72.87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hay wrapping, raking, and rolling (US $ per acre)†</td>
<td>20.10 20.10 20.10 20.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hay baling (US $ per bale)†</td>
<td>3.20 3.20 3.20 3.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest on operating capital (4.8%)</td>
<td>295.25 295.25 295.25 295.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxes and insurance (1% of total investment)</td>
<td>295.25 295.25 295.25 295.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hay prices per ton</td>
<td>118.00 118.00 118.00 118.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>120.00 120.00 120.00 120.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birdsfoot trefoil</td>
<td>100.00 100.00 100.00 100.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meadow bromegrass</td>
<td>120.00 120.00 120.00 120.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meadow bromegrass-legume mixture</td>
<td>100.00 100.00 100.00 100.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Adair et al. 2017; ‡Peterson 2015; USDA NASS 2018
Results

Forage Yield and Nutritive Value

Monoculture and mixture treatments affected forage dry matter yield (Table 3). There was a trend of higher forage yield from mixtures compared to legume and grass monocultures. This was particularly evident in the 50-50% and 70-30% mixtures of meadow bromegrass with alfalfa and 70-30% mixture of meadow bromegrass with birdsfoot trefoil. Same applied to 50-25-25% mixture of meadow bromegrass, alfalfa, and sainfoin; 50-25-25% mixture of meadow bromegrass, alfalfa, and birdsfoot trefoil; and 50-16.7-16.7% mixture of meadow bromegrass, alfalfa, birdsfoot trefoil, and sainfoin. Sainfoin monoculture had lowest forage yield. Treatments also affected forage nutritive value. There was a trend of higher nutritive values in monoculture legumes and mixtures compared to monoculture meadow bromegrass (with or without N). In general, mixtures had similar nutritive value to monoculture legumes.

Table 3. Total forage dry matter (DM) yield and average nutritive value for grass-legume mixtures and nitrogen (N) treatments from different harvests at University of Wyoming Sheridan Research and Extension Center during 2015 to 2017.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>DM yield</th>
<th>Forage nutritive value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2015</td>
<td>2016</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td>Alf (100)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>SF (100)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>BFT (100)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>MB-SF (50-50)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>MB-SF (70-30)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>MB-BFT (50-50)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>MB-BFT (70-30)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>MB-Alf-SF (50-25-25)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MB-Alf-BFT (50-25-25)</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>MB-Alf-BFT-SF (50-16.7-16.7)</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>MB-N0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>MB-N50</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MB-N100</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Economic Benefits of Different Crops

†MB = meadow bromegrass; Alf = alfalfa; SF = sainfoin; BFT = birdsfoot trefoil; N0 = 0 pound N per acre; N50 = 50 pounds N per acre; N100 = 100 pounds N per acre.
‡ CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; IVDMD = in vitro dry matter digestibility; TDN = total digestible nutrients; RFV = relative feed value.

Year and monoculture and mixture treatments influenced GM (Table 4). The 50-50% mixture of meadow brome with alfalfa had the highest four-year total GM of US $1497 per acre. This was similar to GM for 50-25-25% mixture of meadow bromegrass, alfalfa, and birdsfoot trefoil (US $1440 per acre) and 70-30% mixture of meadow bromegrass with alfalfa (US $1368 per acre). Sainfoin monoculture earned the lowest total GM of US $62. All treatments had an increase in GM in the year 2015 compared to 2014 when no enterprise had profits. In subsequent years, some mixtures maintained a consistent increase in profits, for example, the 50-50% mixture of meadow bromegrass with alfalfa (US $241 to $802 per acre) and 70-30% mixture of meadow bromegrass with alfalfa (US $313 to $753 per acre). There were no significant gains in profits for meadow bromegrass monoculture with or without N fertilizer from 2015 to 2017.
Table 4: Operation costs, revenue, and gross margin for different grass-legume mixtures and nitrogen (N) fertilizer rates determined during the years 2014 to 2017 at the University of Wyoming Sheridan Research and Extension Center.

<table>
<thead>
<tr>
<th>Treatments†</th>
<th>Operation costs</th>
<th>Revenue</th>
<th>Gross margin‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>--------------</td>
<td>--------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Alf (100)</td>
<td>397</td>
<td>110</td>
<td>117</td>
</tr>
<tr>
<td>SF (100)</td>
<td>399</td>
<td>104</td>
<td>100</td>
</tr>
<tr>
<td>BFT (100)</td>
<td>368</td>
<td>110</td>
<td>112</td>
</tr>
<tr>
<td>MB-Alf (50-50)</td>
<td>375</td>
<td>111</td>
<td>127</td>
</tr>
<tr>
<td>MB-Alf (70-30)</td>
<td>371</td>
<td>115</td>
<td>119</td>
</tr>
<tr>
<td>MB-SF (50-50)</td>
<td>368</td>
<td>107</td>
<td>111</td>
</tr>
<tr>
<td>MB-SF (70-30)</td>
<td>370</td>
<td>109</td>
<td>109</td>
</tr>
<tr>
<td>MB-BFT (50-50)</td>
<td>346</td>
<td>110</td>
<td>118</td>
</tr>
<tr>
<td>MB-BFT (70-30)</td>
<td>362</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>MB-Alf-SF (50-25-25)</td>
<td>367</td>
<td>112</td>
<td>115</td>
</tr>
<tr>
<td>MB-Alf-BFT (50-25-25)</td>
<td>356</td>
<td>116</td>
<td>128</td>
</tr>
<tr>
<td>MB-Alf-BFT-SF (50-16.7-16.7)</td>
<td>361</td>
<td>114</td>
<td>120</td>
</tr>
<tr>
<td>MB-N0</td>
<td>355</td>
<td>111</td>
<td>110</td>
</tr>
<tr>
<td>MB-N50</td>
<td>394</td>
<td>152</td>
<td>154</td>
</tr>
<tr>
<td>MB-N100</td>
<td>416</td>
<td>186</td>
<td>190</td>
</tr>
</tbody>
</table>

†MB = meadow bromegrass; Alf = alfalfa; SF = sainfoin; BFT = birdsfoot trefoil, N0 = 0 pound N per acre; N50 = 50 pounds N acre; N100 = 100 pounds N per acre.

‡Annual total gross margin from three harvests.


Discussion [Conclusions/Implications]
The study showed that mixtures that include alfalfa and birdsfoot trefoil have potential for higher production and similar market value as good quality pure alfalfa hay (Adjesiwor et al., 2017). Grass-legume mixtures can recoup the investments and still earn profits (Dhakal 2005). In four years, mixtures with alfalfa dominated the most productive and profitable crops overriding changes in weather conditions and management (Dhakal 2005; Adjesiwor et al., 2017). The most promising forage production enterprises were 50-50% mixture of meadow bromegrass with alfalfa, 50-25-25% mixture of meadow bromegrass, alfalfa, and birdsfoot trefoil, and 70-30% mixture of meadow bromegrass with alfalfa. Although mixtures purely comprised of meadow bromegrass and sainfoin had relatively lower gross margins, this crop may have more value considering that sainfoin enhances forage palatability and prevents bloat.

Acknowledgements
We acknowledge the farm crews at the Sheridan Research and Extension Center for their assistance in study maintenance and data collection.

References


THEME 7: CAPACITY, INSTITUTION AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS

Topic: Management, land use planning and ecosystem services
Water use efficiency and land cover variability on a native grassland ranch on the pampa biome of Uruguay

Restrepo-Osorio, Diana. L; De Oliveira, G; Coll, J; Schossler, D
1The University of Kansas (now with the U.S. Geological Survey), 1217 Biltmore Drive Lawrence, Kansas 66049 dreestrepo-osorio@usgs.gov;
2Universidad de la República del Uruguay.

Key words: native grasslands; livestock production; pampa biome; sustainable cattle ranching.

Abstract
Global efforts towards sustainable cattle ranching should be based on comprehensive approaches, targeting physical variables of the ranching process, as well as, the socioeconomic dimensions. Alianza del Pastizal is a non-profit conservation organization that works to preserve the temperate grasslands of the Southern Cone of South America by promoting conservation practices among ranching communities in Uruguay, Paraguay, Argentina, and Brazil. Alianza has become a mediator for ranchers exchanging information, resources, and education. Ranchers associated with the Alliance take pride in their property management as they aim to improve the community wellbeing and natural resource sustainability. In a previous study, producers from the four countries in the Alliance engaged in focus groups and participatory workshops where they identified water cycle regulation and water quality, as the most important ecosystem services provided by natural grasslands on their properties. With this information, our ultimate goal is to determine if the producers actual land use management activities align with the importance they placed on water. For this purpose, we chose the properties located in the floodplain of the Queguay River, northwestern Uruguay. We used a Google Earth Engine platform to inventory the vegetation types and corresponding Water Use Efficiency (WUE) values per vegetation type in the Colonia Juan Gutiérrez. Our results indicate the presence of various vegetation types in the Colonia properties, which follow the seasonal rainfall and temperature patterns of the region, and display variability in WUE values. We plan to carry out the same analysis in the Rincon de Perez conservation area, and the managed forests west of the Colonia. Ultimately, we plan to compare these results to properties that do not subscribe to the Alianza’s ideas to determine whether the stated preferences of Alianza ranchers align with differences in practice that improve environmental outcomes.

Introduction
Ranchers in the Colonia Juan Gutiérrez face significant seasonal challenges with water management for livestock watering due to the drought events of summer and flooding events of winter. These situations are predicted to worsen due to climate change, in addition to, the negative effects that expanding managed forests in the headwaters of the Queguay Grande river tributaries will have on the water cycle of the watershed (Restrepo-Osorio, 2020, Ch 3). In this paper we inventoried the land cover vegetation types in the Colonia properties and investigated if there were differences in water use efficiency (WUE) among the vegetation types. This information may provide insights regarding the vegetation types that could have an important effect on the regulation of the water cycle in the watershed and therefore play an important role in the drought and flood cycles affecting ranching communities in the area. Water use efficiency (WUE) is defined as the ratio of carbon assimilated for gross primary production (GPP) to water loss from the system through seasonal or annual evapotranspiration (ET) (de Oliveira et al., 2018; Tang et al., 2014). We used the equation proposed in Beer et al., (2009); WUE=GPP/ET. Above ground GPP is the gross primary productivity in g cm⁻² and ET is the evapotranspiration in kg H₂O (Beer et al., 2009; Oliveira et al., 2018). According to Brunsell et al., (2014) this equation is commonly used to explore relationships between the water cycle and terrestrial carbon (Brunsell et al., 2014; de Oliveira et al., 2018). Evaporation, which is dependent on solar radiation, can be separated into three elements: 1) water that infiltrates into the soil, then is absorbed by plants and transpired to the atmosphere, 2) water intercepted by foliage
which then evaporates into the air, and 3) water which is intercepted by litter on the soil surface, then infiltrates into the litter, then into the soil, and then evaporates (de Oliveira et al., 2017; Wilcox et al., 2017). Transpiration is the main factor of evapotranspiration over land and it is connected to vegetative productivity (Monteith, 1988; Nosetto et al., 2011). GPP is directly proportional to carbon assimilation (Beer et al., 2009). WUE values change with annual seasonal variability typically displaying higher values during the wet seasons and lower values during the dry season, dependent on ET patterns (de Oliveira et al., 2017). Given that GPP is directly proportional to WUE, it also follows seasonal precipitation patterns. A study carried out in the Amazonia of Brazil indicated that during the low water availability and high ET of the dry season, GPP decreased due to increased stomatal closure and therefore decreased photosynthetic rates (de Oliveira et al., 2017). In a different study, Bathurst (2018) found that during the winter season, watersheds become saturated, there is little infiltration, and evapotranspiration is low (Bathurst et al., 2018), therefore biomass production and WUE decreases.

Materials and Methods

Uruguay is part of the southern cone of South America and it is located between the latitudes 30° and 35° South. Uruguay temperatures increase from the southeastern coast of the country to the southwestern departments. According to 1961-1990 records from the Uruguayan Meteorological Institute, the thirty-year normal temperature for the country is 63.5°F with an average maximum temperature of 66.2°F over the Artigas department, and an average minimum temperature of 60.8°F over the Atlantic coast of the Rocha department (INUMET, n.d.-a). Annual average precipitation ranges from approximately 43.3in in the southwestern departments to approximately 63in in the Rivera department (INUMET, n.d.-a). The center of the Paysandú department is approximately located in the -32.34° latitude and -58.0° longitude in the northwestern area of Uruguay. According to records from 1961-1990, Paysandú’s 30-year normal annual temperature is 64.2°F, with an annual maximum temperature of 108.3°F and an annual minimum temperature of 23.9°F. According to INUMET records from 1961 to 1990, the annual average precipitation in Paysandú during those years was 48in with a maximum 5.8in in the month of March and a minimum of 2.7in in the month of June (INUMET, n.d.-a). Precipitation patterns in Colonia Juan Gutiérrez from 1901 to 2016 follow the general national seasonal trend but deviate in magnitude. Records show a maximum of 5in in April and a minimum of 3.2in in July. Uruguay has two high precipitation periods during the year. The period of precipitation with most rainfall occurs during the fall, and another period with lower rainfall occurs during the spring. The first period reaches its peak in April, which is halfway through fall, and the second period reaches its peak in October, which is halfway through spring. Precipitation in the Colonia Juan Gutiérrez follows this pattern; however, the precipitation events present a larger magnitude than the national monthly mean average. Temperature in the Colonia closely follows the national temperature deviating minimally in the summer when temperatures go up to 76.55°F. Winter temperatures in the Colonia do not seem to deviate much from national temperatures and go as low as 52.86°F.

Temporal Evapotranspiration Aggregation Method (TEAM) Tool

TEAM is a Google Earth Engine tool developed in 2019 by Jim Coll in collaboration with Gabriel de Oliveira. Both coauthors assisted in the development of this project as it is the second application of the TEAM tool in an academic setting, and the first time the tool will be used in the temperate grassland habitat of South America. Previous studies have validated MOD16A2 and MOD17A2H data sets using flux towers in the Brazilian Amazonia to compare WUE, GPP, and ET values in agricultural, primary and secondary tropical forests, and pastureland cover types (de Oliveira et al., 2017). The data presented an average error of ~11% for MODIS16A2 and ~13% for MODIS17A2H when compared to flux tower ground measurements. De Oliveira et al., (2017) found that MODIS presents higher accuracy for forest land cover compared to pasture land cover type (de Oliveira et al., 2017). We used TEAM to assess the land cover composition and distribution surrounding the Colonia Juan Gutiérrez, and to obtain the WUE values. Water Use Efficiency is defined as the ratio of carbon assimilated as biomass production Gross Primary Productivity (GPP), to the units of water used by vegetation Evapotranspiration (ET). TEAM uses MOD16A2 and MOD17A2H (500 m pixel) data sets to carry out its functions (Coll, 2019). TEAM calculates WUE using MOD16A2 for an 8-day composite of GPP and an 8-day composite for ET using MOD17A2H from 2001-2018. For this purpose, the shapefiles of the property boundaries and paddock distribution were obtained from the president of the Sociedad de Fomento Rural de la Colonia Juan Gutiérrez (Development Society of the Juan Gutiérrez Colony). These shapefiles
were imported into the TEAM platform and made them available as a custom shapefile under the unit to aggregate feature (Coll, 2019). The IGBP land cover classification MCD12Q1 database was selected in the land cover feature of the TEAM tool and the custom shapefile under the unit to aggregate feature was selected.

**Colonia Juan Gutiérrez Properties**

The zoom feature was used to frame the polygons outlining the properties in the Colonia Juan Gutiérrez. WUE was chosen as the variable to view, the mean was chosen for the temporal stat to aggregate, the spatial stat to aggregate, and the table stat to aggregate. The year-to-view was left as default, the images to animate were left as the default of 24, and the timestep (ms) was also left as the default 1000. Each one of the 145 polygons outlining the paddock distribution in the Colonia properties were selected. The WUE values for all vegetation types in the properties were displayed in time series and monthly aggregate graphs, both of which were exported as PNG and CSV files to record the WUE for all vegetation types in the ranches. All CSV files were compiled on Google Sheets to obtain a monthly mean WUE, and create graphs of the WUE of each vegetation type in the Colonia properties.

**Results**

![Graph showing WUE aggregated values for vegetation types in Colonia Juan Gutiérrez properties from 2001-2018](image)

**Figure 1:** TEAM tool WUE aggregated values for vegetation types in Colonia Juan Gutiérrez properties from 2001-2018

**Table 1:** WUE mean of minimum values and mean of maximum values for the vegetation types in the Colonia Juan Gutiérrez properties, and overall monthly mean WUE per vegetation type.

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>WUE (g C Kg⁻¹ H₂O)</th>
<th>Monthly mean WUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woody savannas</td>
<td>1.14</td>
<td>1.76</td>
</tr>
<tr>
<td>Savannas</td>
<td>1.38</td>
<td>1.76</td>
</tr>
<tr>
<td>Evergreen broadleaf forest</td>
<td>1.39</td>
<td>1.92</td>
</tr>
<tr>
<td>Grasses</td>
<td>1.60</td>
<td>1.92</td>
</tr>
</tbody>
</table>

**Water use efficiency of vegetation types in Colonia Juan Gutiérrez properties**

The WUE analysis of the vegetation types on the properties of the floodplain of the Queguay Grande river and the properties of the floodplain of the Queguay Chico river, both part of the Colonia Juan Gutiérrez, show that most values follow a similar pattern. WUE seems to increase from January to March where it steeply increases and decreases in July after which it increases again and then slowly decreases from October until the end of the year (Figure 1). The evergreen
broadleaf forest WUE is higher than the rest of the vegetation types with a WUE of 2.37 g C Kg⁻¹ H₂O, whereas woody savannas in the properties had the lowest WUE value of 1.14g C Kg⁻¹ H₂O. Evergreen broadleaf forests and grasses had the highest monthly mean WUE of 1.92g C Kg⁻¹ H₂O, and woody savannas and savannas had the lowest monthly mean WUE of 1.76g C Kg⁻¹ H₂O (Table 1).

**Discussion**

Different vegetation types react differently to the seasonal variations in precipitation and temperature and therefore regulate the water cycle in different ways. This is of special interest to ranchers and other land managers in the Queguay Grande river watershed, given the history of seasonal flooding and drought that affect the ranching enterprise and the livelihood of ranching families. In general, evergreen forest species maintain their leaves during the winter; therefore, water flux processes can still occur with little disruption compared to deciduous species that become dormant during the winter. The production of biomass by evergreen species, or GPP, is ongoing, therefore it results in higher WUE values compared to other vegetation types in the properties. Given that the relationship between GPP and WUE is directly proportional, a high GPP is often reflected in a high WUE. Therefore, since the evergreen broadleaf forest species in the Colonia Juan Gutierrez properties remain active during the winter using water for biomass production, they could influence water cycle dynamics in the watershed during that season. Woody savanna vegetation types identified in the Colonia properties could be an indication of a serious problem involving woody encroachment of potential exotic species from nearby managed forests and having effects in the water dynamics in the watershed. This could become a threat to the efforts of several local and national conservation organizations, including the Alianza del Pastizal, which works to preserve the native grasslands of the Pampa biome. Intentional or unintentional land conversion of temperate grasslands to forests would jeopardize the livelihood of the ranching communities in the Colonia Juan Gutiérrez. Woody encroachment management should become a priority for conservation nonprofit organizations, and associated local and national governmental organizations such as the Ranching, Agriculture, and Fishing Ministry of Uruguay, to collaborate and provide the necessary tools for ranchers to adapt, mitigate and become resilient to negative effects derived from climate change.

**Acknowledgements**

CLACS at the University of Kansas for the Pierre A.Stouse Jr.Memorial Award, Robert Oppenheimer Memorial Scholarship, and Tinker Field Research Grant. The Grassland Alliance, Guyra Paraguay, Aves Uruguay, AUGAP, Colonia Juan Gutiérrez, Sociedad de Fomento Rural de la Colonia Juan Gutiérrez, and all participants.

**References**


Revisiting the concept of the planning region in settings with dynamic spatial-temporal conditions: Lessons from land use planning in pastoral areas of Kenya, Ethiopia and Tanzania

Musoga, H.1; Robinson, L.W.2

1 Kenya National Land Commission; 2 Ruwaza Sustainable Development Ltd.

Key words: Land governance; Land Use Planning Units; Pastoralists; Planning Region; Scale mismatch.

Abstract

Pastoralist rangeland systems often provide prime examples of scale mismatch—the challenge that arises when decision-making institutions' scale and geographic extent do not correspond to the scale and geographic extent of problems that need to be addressed.

Pastoralist resource use and traditional governance systems operate at multiple levels and are often characterized by overlapping claims, rights, and management territories.

Scholarship on pastoralist systems suggests that their fuzziness, flexibility, and overlap in territories and rights mean that no single scale or level is optimal for effective resource governance. These characteristics stymie attempts to implement conventional land governance systems in pastoralist areas. Land use planning represents an approach to land governance that can address some of the challenges of pastoral systems, but only if the challenge of scale can be addressed. Land use planning is a process that has to be applied over a set of particular—usually clearly-defined—spaces: planning units and regions. An essential step in the land use planning process is interpreting the site to delimit the planning area and determine the appropriate planning units. This paper considers the question of how to apply the concept of a planning region in land use planning in pastoral settings. Land use planning interventions that use simplistic delineations of planning units and regions run the risk of fragmenting pastoral systems and compounding scale mismatch. The paper describes how frameworks for land use planning in pastoral areas now being rolled out in three different countries in East Africa address this problem. The strategies adopted are explicitly planning at multiple levels with cross-level linkages and planning with multiple, overlapping kinds of planning units.

The challenges of land governance in pastoral systems

The highly variable and ephemeral nature of resources in pastoral settings compel a livelihood strategy that is flexible, responsive, and often opportunistic.

Resources are often shared, willingly or unwillingly, among social groups with overlapping and sometimes competing claims over land and resources. Customary pastoral governance reflects this, often characterized by boundaries, rights, rules and social groupings that are fuzzy (not clearly defined) and flexible (easily and frequently relaxed or adjusted; Niamir-Fuller 1999, Goodhue and McCarthy 2000, Fernández-Giménez 2002). At the same time, pastoral lands are highly vulnerable to alienation, conversion to other uses, and fragmentation and require land governance frameworks that can create secure tenure. However, mainstream approaches to strengthening land governance, focusing on the clear demarcation of boundaries and clear allocation of rights and responsibilities, tend to undermine the fuzziness and flexibility essential to pastoral systems. This conundrum is the paradox of pastoral tenure (Fernández-Giménez 2002).

The related problem is scale mismatch, which results when the jurisdictional or administrative scale of decision-making does not correspond to relevant biophysical or social-ecological scales of real-world problems (Cash et al., 2006). It has been suggested that pastoral rangelands are particularly prone to scale mismatch (Robinson et al., 2017, Unks et al., 2019).

Given the difficulties inherent in strengthening land governance in pastoral settings through strategies focused on clearly defined boundaries and secure tenure, alternative approaches must
be considered. It has been suggested that as a tool for land governance, land use planning is particularly suited to pastoralist settings, fitting well with customary pastoralist practices (Tefera et al., 2016). In addition, land use planning tends to have more of a process orientation than interventions that emphasize tenure. This is not to deny that secure land tenure is important for pastoral systems, but to argue that there is much to be gained by investing more in land use planning in these systems.

When land-use planning is undertaken over large territories, an essential step in the planning process is interpreting the territory to delimit the planning area and determine the appropriate planning units. However, effectively using planning regions within the land use planning process requires adaptations to the unique social, political and biophysical characteristics of each setting. This paper considers the question of how to apply the concept of a planning region in land use planning in pastoral settings.

**Critical challenges in pastoral rangelands that land-use planning must consider**

**Multi-level and multi-scale dynamics**

In pastoral communities, resource use can be understood at different levels. Consequently, customary pastoral decision-making also tends to involve multi-level processes. However, while there may be effective local-level institutions in some places, customary systems for managing resources at a large landscape scale have eroded, creating critical gaps in governance. It is also important to note that a single, hierarchical understanding of nested levels can often be simplistic. There can be different kinds of overlapping and competing scales (Robinson et al., 2017). For example, different social groups can use the same resources in different ways. In addition, institutions with different geographic mandates overlap in space in complex ways. These kinds of relationships that are both multi-level and cross-scale should be considered in land use planning processes.

**Conflict.** Conflict is a recurring issue in pastoral settings. This can take the form of conflict among different pastoral groups, conflict with agriculturalist communities, conflict with the state, or sometimes a combination of these. Access to and use of land can be a driver of such conflicts, but such conflicts are almost always complex, potentially involving various dimensions such as ethnicity, religion, livelihood, and political alliances. Of particular relevance to land use planning is the spatial nature of such conflicts.

**Lack of reliable resource rights.** The importance of rangelands to pastoralists is notoriously undervalued.

State land tenure frameworks and other policies often treat these lands as underutilized, vacant land that can only be secured when someone for a narrow interest claims it—for individual rather than a collective benefit—for example, by fencing and/or ploughing it. When the portions of collective rangelands being alienated are critical, “linchpin” resources such as drought reserve pastures, the consequences for livestock-based livelihoods can be devastating. The lack of reliable rights also undermines attempts at sustainable resource management. Land-use planning can contribute to reversing this situation.

**Fuzziness, flexibility and resource sharing.** As mentioned above, customary pastoralist systems tend to involve flexible institutions, fuzzy and flexible resource boundaries and social group boundaries. These are adaptations to climates in which the variability of rainfall and forage across space and time is a key driving force. Attempts to strengthen resource rights should not undermine the essential flexibility of pastoral systems.

**Land use planning in East Africa and the role for planning regions**

In East Africa, for many years, state-run land use planning processes, if they happened at all, focused solely on urban planning. However, frameworks for land use planning in rural areas and over larger territories have been established in Ethiopia, Kenya and Tanzania. These include woreda (district) and county-level planning processes in Ethiopia and Kenya. For example, in Tanzania, there is village level land use planning, but in pastoral areas, because of livestock mobility, several villages may be grouped for joint village land use planning at a larger scale. All three processes contribute or at least have the potential to improve security for common-pool grazing land. In Tanzania, for instance, the joint village land use plan can result in the issuance of Certificates of Customary Rights of Occupancy (CCROs). Similarly, guidance materials for carrying out the county spatial planning process in Kenya’s pastoral areas refer to the County Spatial Plan as a means of “giving legal weight to planning that communities have already done” (Musoga et al., 2019: 11).

While land-use planning has the potential to bring attention to the relationships among different pieces of land and complex dynamics within larger landscapes, no planning process can focus on all issues and all places all of the time—at
some point, the overall planning process needs to be divided into smaller manageable bits. One way to do this is by dividing an overall target area into planning units or planning regions. Wannop (1995: 403) appropriately states that “regional planning arises because of cross-boundary issues and tensions inevitable with any pattern of governance, regardless of whether or not it matches geographical regions.” Therefore, a planning region refers to the sub-national space/unit so delimited to show the area targeted for undertaking the land use planning process. This planning region is defined depending upon the planning issues or objectives to be articulated. It offers a certain flexibility that suits the pastoral cross administrative boundaries economy quite well.

In Kenya, the county spatial planning process explicitly envisions identifying a number of planning regions. Referred to as “Planning Areas”, this step involves considering pastoral land use and taking a landscape perspective. The identification of planning areas is based on considerations such as the existing customary resource management territories and institutions, pre-existing resource management systems such as inter-community grazing agreements, pastoral mobility, and patterns of regular interactions and resource sharing among different ethnic communities and groups. In addition, one of the recommendations in the CSP guidance materials is to consider how public participation will be conducted and the ease or difficulty of bringing communities and stakeholders together—public participation processes will become more difficult and costly if planning areas are too large.

Like interventions focused on land tenure, the use of planning regions in land use planning is also susceptible to scale mismatch if applied in a way that does not consider the spatial realities of livelihoods, resource use, problems and opportunities. Land use planning interventions that use simplistic delineations of planning units and regions run the risk of fragmenting pastoral systems and compounding scale mismatch.

**How to conceive of planning regions in pastoral settings**

From the above discussion and a reading of the literature on pastoral land and resource governance and land use planning, we propose four principles for planning regions in land use planning processes in pastoral settings.

The first is to use planning regions to overcome scale mismatch. Since much of the decision-making that affects pastoralists already takes place according to existing administrative jurisdictions such as counties or sub-counties, and other considerations such as ecosystem integrity, wildlife migration, livestock migration, and customary land planning systems are often ignored, it will make sense to delineate planning regions not according to administrative boundaries but instead prioritizing these other considerations when creating planning regions. However, there is no single best way to delineate planning regions. This suggests a multi-layered approach to planning regions, in which different kinds of overlapping planning regions are used throughout the land use planning process. The multi-layered approach can create possibilities for planning to address issues that cut across administrative, watershed, ethnic and other boundaries, just as pastoralist mobility often cuts across these boundaries.

The second principle is to use planning regions to strengthen land governance while still embracing the flexibility of pastoral systems. While not the same as interventions directly focused on recognizing communal land tenure, land use planning processes can be used to strengthen tenure rights, as seen with the Tanzanian CCROs. Combining this sort of protection for land resources with the flexible, multi-layered approach to planning regions has the potential to strengthen land governance without succumbing to the paradox of pastoral tenure.

Thirdly, planning regions can be used as a tool to bring different communities and stakeholders together around shared resource use areas and conflict hotspots. This could be different pastoralist groups in conflict with each other or with other stakeholders such as farmers, conservation authorities, or others. A spatial definition of a conflict “problemshed” can be used to identify a planning region through which pastoralists and other stakeholders interact to address conflicts.

The fourth principle is to use planning regions to build the capacity of stakeholders to engage in spatial planning. Having at least one layer of planning created areas at a relatively small scale can help to enable multi-stakeholder participation processes that are highly interactive, creating the opportunity to generate a grassroots connection to the land use planning process and strengthen trust. However, public participation should not be strictly structured according to any single delineation of planning regions. Vision setting, analysis, prioritization and other steps in the planning process within each planning region must also look beyond to neighbouring areas. This kind of participatory planning at local levels, but connected to various layers of planning at larger scales, can be a long-term investment into building capacity for planning that can eventually feed into planning at higher levels.
Acknowledgements
This paper and some of the work that it refers to were carried out with funding support from the CGIAR Research Programs on Livestock.

References


Adaptive, multi-paddock, rotational grazing management: An experimental, ranch-scale assessment of effects on multiple ecosystem services

Augustine, D.J.1; Derner, J.D.1; Porensky, L.M.1; Wilmer, H.2; Fernández-Giménez, M.4; Briske, D.D.5

1 USDA-ARS Rangeland Resources and Systems Research Unit, Fort Collins, CO USA; 2 USDA Forest Service Pacific Northwest Research Station, Juneau, AK USA; 3 USDA-ARS Rangeland Resources and Systems Research Unit, Cheyenne, WY USA; 4 Department of Forest and Rangeland Stewardship, Colorado State University, Fort Collins, CO USA; 5 Department of Ecology and Conservation Biology, Texas A&M University, College Station TX USA

Key words: collaboration; ecosystem services; semi-arid rangeland; shortgrass steppe

Abstract
Decisions on how to move livestock in space and time are central to rangeland management. Despite decades of small-scale research, substantial uncertainty exists regarding the relative importance of cattle stocking rates per se, versus the movement of cattle in both space and time, in achieving desired vegetation and livestock outcomes at scales relevant to livestock producers. We report on a ranch-scale experiment comparing effects of collaborative, adaptive, multi-paddock, rotational management (CARM) versus more traditional, season-long, continuous rangeland management (TRM) on perennial grass density and production, cattle performance, and wildlife habitat, while holding the annual stocking rate the same in both systems. We collaborated with stakeholders to develop an adaptive grazing management plan, collected pre-treatment data in 2013, and implemented treatments during 2014 – 2020. Results for 2014 – 2018 were reported by Augustine et al., (2020); here we report on two additional years of results, covering a 7-year period of treatments from 2014 – 2020. With two additional years of measurements, we found no significant difference in total forage production in CARM vs. TRM treatments, averaged across all soil types in the experiment. In one year, we found that CARM increased forage production on loamy soils and decreased forage production on alkaline soils, but these differences were minor and in opposite directions, resulting in no net overall effect. Furthermore, we found that adaptive, rotational grazing management substantially reduced livestock weight gains in each of the first 6 years of the experiment, when cattle were managed as a single, large herd occupying each paddock sequentially. Across the 6 years, cattle weight gain averaged 15% lower in CARM vs. TRM. In the 7th year, stocking density in CARM was reduced 50% by giving cattle access to two paddocks at a time. This year also coincided with a drought. Under these conditions, cattle weight gains were identical in both treatments. Results emphasize the importance of replicated controls in assessing grazing management effects. Even in heterogeneous landscapes where livestock are moved adaptively among paddocks to match seasonal patterns of forage growth, such management may not lead to desired outcomes for vegetation and livestock.

Introduction
Few studies have examined the effects of adaptively managed rotational grazing systems in heterogeneous and spatially extensive landscapes (Briske et al., 2008; Hawkins et al., 2017; Teague and Barnes 2017). Livestock distribution on the landscape is typically managed via fencing and water infrastructure, which can be costly, yet experimental studies addressing the ecological and economic benefits of such management remain rare. A South African study did not find any benefits to vegetation or livestock production arising from rotational versus season-long grazing regimes (Venter 2019). In North America, Teague et al., (2011) found that adaptive, multi-paddock grazing at ranch scales enhanced soil organic matter and vegetation composition relative to long-term continuous grazing, but did not evaluate livestock production. A synthesis of research in Australian rangelands concluded that complex, multi-paddock, rotational grazing systems were not appropriate for the region, but that moderate stocking rates and provision of periodic growing-season rest from grazing were essential to...
maintaining rangeland condition (O’Reagain et al., 2014).

Here, we report on a grazing management experiment that incorporates study design recommendations discussed by Teague and Barnes, (2017) to examine the effects of adaptive, multi-paddock, rotational grazing management on vegetation and livestock production in a semi-arid rangeland. Results of the first five years of the experiment were recently reported by Augustine et al., (2020); here we report on two additional years of results, covering a 7-year period of treatments from 2014 – 2020. Decisions regarding annual stocking rate and the sequence and timing of cattle movements among paddocks for the adaptive, multi-paddock grazing were made by an 11-member stakeholder group seeking to achieve a suite of vegetation, livestock, and wildlife and objectives (see Wilmer et al., 2018); this experimental treatment is hereafter referred to as Collaborative Adaptive Rangeland Management (CARM). For CARM, the 10, 130-ha paddocks were grazed by a single, herd of steers managed using adaptive, rotational grazing which incorporated planned year-long rest in 20% of the paddocks. For TRM, 10 paired, 130-ha paddocks experienced season-long, continuous grazing by herds of yearling steers at one-tenth the stocking density of the single CARM herd. Overall stocking rates for both treatments were identical. We hypothesized that periodic, year-long rest from grazing in the CARM treatment would increase forage production, and that the adaptive nature of the rotational management system would compensate for negative effects of high stock densities to yield similar livestock performance as in TRM.

Materials and Methods
Research was conducted at the Central Plains Experimental Range (CPER) in northeast Colorado, USA (40°50’N, 104°43’W). Long-term mean annual precipitation on the CPER is 340 mm. Topography is flat to gently rolling; soils range from fine sandy loams on upland plains to alkaline salt flats bordering drainages. Two C4 shortgrass species comprise over 70% of aboveground net primary productivity (Lauenroth and Sala 1992). Twenty 130-ha paddocks were paired into ten blocks where each block contained two paddocks similar in terms of soil and plant characteristics, topographic patterns, and prior management history. One paddock in each pair was randomly assigned to the TRM treatment. Each TRM paddock was grazed throughout the growing season (mid-May to early October) by a single herd of yearling steers. The other was assigned to the CARM treatment (Fernandez-Giménez et al., 2019). Each TRM paddock was grazed (i.e., none were rested) by a herd of yearling steers that occupied each paddock separately, whereas the CARM paddocks were grazed by a single 10-fold larger herd of steers managed with an adaptive, rotational grazing system, with 20% of the paddocks planned for year-long rest each year (Fernández-Giménez et al., 2019). Details of the cattle management strategy applied to the CARM paddocks were developed by the 11-member stakeholder group who used stocking rate adjustments, grazing rotations, and season-long rest to help achieve specific goals and objectives (Wilmer et al., 2018).

Paddocks were stratified by ecological site and topography. We established four pairs of plots in the seven experimental blocks containing loamy and/or sandy plains ecological sites, and six pairs of plots in three blocks that additionally contained the salt flat ecological site. We measured aboveground net primary production (ANPP) of plant functional groups (C4 perennial grasses, C3 perennial graminoids, annual grasses, forbs, and subshrubs) at peak biomass in August, with harvests occurring in a 0.18 m² rectangular quadrats within four 1 x 1 m moveable grazing cages per plot. For analyses of forage production, we treated both 2013 and 2014 as pretreatment years because the vegetation measurements occurred in grazing cages moved annually, and hence measurements of forage in 2014 could not yet have been affected by the treatment. Forage measurements from 2013 and 214 were averaged at the plot scale and included as a covariate in the linear mixed model to account for pre-treatment variation among plots and paddocks.

The stocking rate was initially 0.61 animal unit months (AUM) ha-1 in 2014. and was adjusted to 0.64, 0.67, 0.70, 0.81, 0.70, and 0.70 AUM ha⁻¹ during 2015 – 2020 respectively. Which CARM paddocks experienced pulse grazing and which were rested from grazing varied across years and depended on an adaptive grazing management plan developed by stakeholders as well as on-the-ground, weather-dependent conditions (i.e., forage biomass and cattle behavior) measured weekly during the grazing season. In response to results from 2014 – 2019, the grazing strategy for CARM was changed for the 2020 grazing season by dividing the CARM cattle into two separate herds, where each was planned to have access to 4 paddocks during the growing season, with the remaining two paddocks rested. This was done to reduce the stock density at any given point time in the CARM treatment to half of the level used in the prior six years. Because 2020 was a drought year, actual grazing implementation required the
cattle to graze all 10 paddocks, and then to regraze several paddocks in order to have sufficient forage for the full extent of the grazing season.

Each year, we weighed steers individually at the beginning of the grazing season (mid-May), stratified steers by weight, and randomly assigned them to TRM and CARM treatments. We individually weighed steers again at the end (early October) of each grazing season. We used shrunk weights (Derner et al., 2016) to determine seasonal gains (kg steer\(^{-1}\)) and average daily gain (kg steer\(^{-1}\) day\(^{-1}\)), calculated as seasonal gain divided by number of grazing days.

**Table 1**: Results of a linear mixed model for annual herbaceous forage production in response to CARM vs. traditional grazing management, year, and ecological site in the shortgrass steppe of northeastern CO.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF</th>
<th>Den DF</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
<td>117</td>
<td>5.35</td>
<td>0.0225</td>
</tr>
<tr>
<td>Year</td>
<td>5</td>
<td>22.7</td>
<td>68.58</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Treatment*Year</td>
<td>5</td>
<td>311</td>
<td>1.19</td>
<td>0.3124</td>
</tr>
<tr>
<td>Ecosite</td>
<td>2</td>
<td>50.8</td>
<td>16.72</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Ecosite*Treatment</td>
<td>2</td>
<td>119</td>
<td>8.22</td>
<td>0.0005</td>
</tr>
<tr>
<td>Ecosite*Year</td>
<td>10</td>
<td>227</td>
<td>1.08</td>
<td>0.3779</td>
</tr>
<tr>
<td>Ecosite<em>Treatment</em>Year</td>
<td>10</td>
<td>336</td>
<td>1.01</td>
<td>0.4314</td>
</tr>
</tbody>
</table>

**Results**

Total production of herbaceous forage (C\(_3\) and C\(_4\) perennial graminoids plus forbs) increased substantially during the wet years of 2014 and 2015, was below average during dry years in 2016 and 2018, and declined to approximately 50% of average production during a drought in 2020. A linear mixed model of annual herbaceous forage production showed no significant 3-way interaction between treatment, ecological site and year (\(P = 0.43;\) Table 1), a significant treatment x ecosite interaction (\(P = 0.0005;\)) and no treatment x year interaction (\(P = 0.31;\) Table 1). The only significant contrasts between treatments arose because forage production averaged 19% lower on the salt flat ecosite in CARM compared to TRM, whereas grazing treatment had no effect on the Loamy Plains or Sandy Plains ecosites (Figure 1).

**Cattle weight gains**

Cattle weight gains in the two grazing treatments were nearly identical in the pretreatment year of 2013. Cattle weight gains were reduced by 13 – 19% in CARM vs. TRM in all of the first 6 years of treatments (2014 – 2019). Averaged across these 6 years, daily weight gains for cattle in CARM were 15% lower than those of TRM (Figure 2). In the 7\(^{th}\) year of the experiment, which coincided with a drought, weight gains were nearly identical in the two treatments (Figure 2).

**Figure 1**: Comparison of total forage production in CARM and TRM treatments during 2015 – 2020 in shortgrass steppe of northeastern Colorado.

**Figure 2**: Effect of grazing management treatments on average daily weight gains (kg steer\(^{-1}\) day\(^{-1}\)) of yearling steers.

**Discussion**

Whether adaptive, multi-paddock rotational grazing management strategies can achieve multiple desired ecosystem services on rangelands has proven difficult to evaluate due to the long-
term and large-scale dynamics involved (Hawkins et al., 2017; Teague and Barnes 2017). Recent assessments of the long-term consequences of rotational grazing systems in Australia and Africa found neutral or negative effects on vegetation and livestock production (Badgery et al., 2017; Venter et al., 2018). We similarly found that 7 years of implementation of adaptive, rotational grazing management by decision-makers provided with detailed vegetation and animal monitoring data did not enhance forage production, and resulted in a substantial loss in season-long weight gain of cattle in 6 of 7 years. During the first 6 years, reduced cattle weight gain in CARM was likely the result of cattle grazing at such a high stock density that they foraged less selectively and acquired lower-quality diets. Ongoing analyses of grazing behavior and diet are evaluating these mechanisms. In the 7th year of study, the stock density in the CARM treatment was reduced 50%, by allowing cattle access to two paddocks at any given point in time rather than one. Weight gains were nearly identical between CARM and TRM cattle at the lower stock density (Figure 2). A drought occurred in the 7th year so we are uncertain whether the reduced stock density (which was still 5 times greater than in TRM) was sufficient to eliminate the difference in weight gain, or if the drought led to such poor forage quality across both treatments that no difference in weight gain could arise due to the stock density difference. Future years of study are needed to disentangle these factors.

The outcomes of CARM appeared to be positive in the absence of direct comparisons to paired TRM paddocks. Forage production increased during the first two years following CARM implementation, the plant community persisted in a desired condition, and stakeholders were able to increase stocking rate during the first four years. These results identify one potential reason multipaddock rotational grazing may be perceived to benefit rangeland condition. However, when these outcomes were directly compared to those of TRM in an experimental framework, we see that similar forage production was also achieved but with greater cattle weight gains in TRM than with CARM. Our results suggest that rangeland managers seeking to implement adaptive, prescribed grazing to achieve multiple ecosystem services should seek to identify sufficiently low stocking densities to sustain desired livestock weight gains and economic returns.

Acknowledgements

We thank the CARM stakeholders for a decade of dedicated commitment to this experiment, and the many USDA-ARS employees who supported data collection and cattle management.

References


Scalable online scenario development tool for rangeland conservancy managers using high spatial-temporal resolution carrying capacity maps and livestock market data


University of Twente, The Netherlands; Consultant, Nairobi, Kenya

Key words: high resolution rangelands modelling; conservancies management; Maasai Mara; remote sensing; cloud-based]

Abstract

Although the management of livestock numbers within the bounds of carrying capacity of African rangelands is a way to manage risks, both scientists and practitioners, caution against a momentary and local use of carrying capacity as a management indicator. Carrying capacity should be seen in wider spatial and temporal/temporal/seasonal context as well as in a social and economic context. Given the large numbers of conservancies across Kenya, and its Maasai Mara region in particular, with many more landowner members, it is difficult for conservancies’ managers to contextualize phenomena such as carrying capacity and market price over space and time.

We report the results of an investigation in the Maasai Mara rangelands, into functional characteristics a tool for spatial-temporal carrying capacity assessment and livestock markets prices monitoring should have to provide relevant management information to conservancy managers and conservancy members. A scalable web-application called the Mara Rangeland Information System, or MARIS, was developed, which assesses, at 23 meter resolution and 10 day historic or 1-day near-future intervals, both grassland dry matter production, and consumption by 19 wildlife and livestock species, as well as rangeland carrying capacity. MARIS facilitates managers to develop scenarios by varying input variables of either grass production or consumption, or by drawing different management blocks on a carrying capacity map assessing different management practices under scenarios of rainfall. Managers can relate the carrying capacity scenarios to offtake prices at different markets that MARIS monitors over time.

After testing MARIS in 6 workshop iterations across the whole development process, Maasai Mara rangeland managers concluded that the prototype is ready for pilot use in management plan development.

Introduction

Kenya has seen a 70% reduction of wildlife since the 1970s due to exponential human population growth, increasing livestock numbers, climatic change, and policy, institutional and market failures (Ogutu et al., 2016) and shocks due to droughts (Nkedianye et al., 2011). Eleven regional associations of conservancies, organized in the Kenya Wildlife Conservancies Association, coordinate 160 conservancies that manage 11% of Kenya’s land, i.e. 6.3 million ha, affect 700,000 households, and aim to turn this trend (KWCA, 2019).

Although the management of livestock numbers within the bounds of carrying capacity of rangelands is a way to manage risks, both scientists and practitioners, caution against a momentary and local use of carrying capacity as a management indicator. They show and argue that carrying capacity should be seen in wider spatial and temporal/temporal/seasonal context as well as in a social and economic context (Briske, Coppock, Illius, & Fuhlendorf, 2020; Jakoby, Quaas, Baumgartner, & Frank, 2015; NRT, 2019). Obviously, conservancy managers and their members do contextualize. Yet contextualization over space and time of phenomena such as carrying capacity or market prices is difficult.

Given the large numbers of conservancies over very large areas and the difficulty for conservancies’ managers to contextualize phenomena such as carrying capacity and market price over space and time, scalable widely accessible tools for understanding of historic and recent development
of carrying capacity and market prices over large areas are in order. Besides the monitoring and evaluation of these management areas, also the development of spatial and temporal scenarios of management alternatives are required. Such tools and methods do not exist yet.

The objective of the work presented in this paper was to develop an online tool together with conservancy managers of the Maasai Mara, that would be scalable to other conservancies in Kenya. The research questions discussed in the short scope of this paper are which functional characteristics such tool should have and whether it provided relevant management information. The work resulted in a web-application called the Mara Rangeland Information System, or MARIS. Development of MARIS took place between 2014 and 2019 within the Mau Mara Serengeti Sustainable Water Initiative.

Materials and Methods

The Maasai Mara reserve, in the Southwest of Kenya, measures approximately 1500 km². Outside the reserve, 15 conservancies have organized themselves in the Maasai Mara Conservancies Association, with 7091 landowners managing an area of 1150 km² (MMWCA, 2020). Landowners lease land to the conservancies, which pay with part of tourism revenues thus providing an income sufficient to close the poverty gap (Osano et al., 2013). In return for this payment, conservancies expect ecosystem services from landowners who collaborate in management plans that conservancies develop, which limit livestock numbers and define pastoral practices.

Although the Maasai Mara is not the driest region in Kenya, past droughts have had a serious impact on livestock herds where 30% of livestock died (Nkedianye et al., 2011). Overstocking is a problem and degradation of grasslands can be found in the North East through vegetation mapping published in these proceedings (Toxopeus et al., 2018). Apart from the pressure of droughts, overstocking (Lovschal, Hakonsson, & Amoke, 2019), and fencing (Lovschal et al., 2017), population growth is, according to Courtney, a time bomb (Courtney, 2016), with 90.8 births/1000 people/annum, compared to 28.3 for Kenya, amounting to a population doubling time of approximately 15 years.

Four algorithms form the core of MARIS, which were elaborated from earlier application in the Amboseli ecosystem, in Kenya (Toxopeus, 1996, 1997). The first algorithm establishes a high resolution (23 meter) pixel floristics vegetation map with percentage grass cover, explained by Toxopeus et al., in these proceedings. Since floristic composition of grasslands is known, nutritious value of dry matter production can be corrected for palatability. The next three algorithms calculate grasses available production, consumption, and carrying capacity. These three algorithms are implemented with the workflow functionality and client-server architecture of the ILWIS 4.0 GIS (Lemmens et al., 2018), calculating dry matter biomass production per 23 meter pixel over a selected period of time. The forage production (gr/m²) for each pixel is a function of rainfall over a certain period of time (mm) derived from a series of satellite products, rainfall effectivity (factor), value depending on soil texture, depth and run on-off (Van Wijngaarden, 1985), percentage grass cover (%), derived from the vegetation map, adjusted for palatability (factor) and proper use (factor) (Hunt, 2008).

Consumption is a function of number of grazers, both wildlife and livestock, and mixed feeders counted annually in dry or wet season by DRSRS aerial survey in the Narok county animal census, distributed with a species distribution model. The numbers of nineteen grass-feeding species in the census, including cattle, sheep and goats, and their daily dry matter intake (DMI) give demand over the selected period.

To estimate the carrying capacity (CC), first wildlife consumption has been subtracted from the total production, the remaining forage is deemed available for livestock. Then this remaining forage has been summed with actual livestock consumption (per pixel), resulting in either a surplus or deficit of forage. Finally, scenario development with either variables of production, or consumption or both can be done. Production can be varied in terms of rainfall, grass cover, palatability and proper use. Consumption can be varied by livestock numbers and their daily DMI. A carrying capacity table shows all possible sums of production and consumption scenarios and corresponding surpluses or deficits.

The central objective of development was scalability and replicability in other Kenyan and African rangelands. To ease scalability and replicability the application uses open-source software. It also uses a continuous stream of open access global satellite data and local empirical parameters. Where internet is limited or off-line, the backend workflow algorithms, can be run on the regular ILWIS desktop GIS, the same software that also runs on the application server. Therefore, calculations can be done off-line.
Results
The MARIS web-application can be found at http://mara.rangelands.itc.utwente.nl/. All output maps of the production, consumption and carrying capacity algorithms and their constituting input maps (Figure 1) are organized in a tree pane (left), and can be seen in a map output pane (middle) and a map input pane (right). Maps synchronously zoom and pan so that areas can be studied in detail and developments in production, consumption and carrying capacity output maps can be understood from their various input maps.

Additional information about time series of rainfall and vegetation greenness are presented in maps of respectively rainfall surplus or deficit or current NDVI and a graph for a selected location, possibly zooming to a period of particular interest, for instance a period of drought, as basis for scenario development (Figure 2). Time series of livestock price development are presented in a scatter plot where for instance price differences of the same cattle breed with the same body condition but in different livestock markets can be observed.

With understanding of the historic states of the grassland and market system as well the near future rainfall forecast, users can develop scenarios for their conservancy. They adjust production and consumption variables according to scenarios they name. These inputs and calculation results are then presented in production and consumption scenario tables and in a cross table showing carrying capacity resulting from all combinations of production and consumption scenarios. For example, conservancy management could assess which of different scenarios of numbers and breeds of cattle in combination with different scenarios of rainfall sum and proper use level would lead to exceedance of carrying capacity. Finally, users can also delineate management blocks on a map, for which production, demand and carrying capacity under current conditions are presented in a bar graph and table.

Figure 1: MARIS interface organized in a tree pane (left), an output map pane (middle) and an input map pane (right). The output map shows carrying capacity exceeds carrying capacity in red areas.

Figure 2: MARIS interface for rainfall where a map and graph show rainfall deficit over space and over time for a selected period and location.
The six workshops with managers from almost all conservancies that steered the development, lead to similar understanding of the concept of carrying capacity, a request for market price monitoring and for location specific temporal overview of rainfall and vegetation greenness. They found that workflows made algorithms transparent and testing lead to a recommendation to pursue funding for piloting in management plan development since MARIS information was deemed relevant.

Discussion
Given the positive response from conservancy managers, the aspiration exists to roll out to other rangeland areas in Kenya. However, validation by conservancies managers through piloting of MARIS in the regular preparation of management plans over several seasons will be necessary to learn and gain experience. Although price differences between markets, breeds and body condition could clearly be observed, the monitoring of those markets has been too short, 1 year, to show price patterns over time.

Scalability is important for roll out of this Rangeland Information System (RIS) to all 160 conservancies in the rangeland areas of Kenya, and beyond. The structure of the workflows can remain the same. The omnipresence of satellite data for rainfall and vegetation greenness would require minor technical adaptation. Also, the collection of market prices does not require major adaptation. The empirical relation for dry matter production appeared to work well in the Maasai Mara but would need validation under different environmental conditions or eco-regions. The main effort would be to develop the floristics composition vegetation map.

MARIS allows conservancy managers to consider the concept of carrying capacity in spatial contexts at different scales due to high-resolution vegetation mapping and in different temporal contexts. Moreover, it provides context of the livestock markets prices over time.

Acknowledgements
We would like to acknowledge the embassy of the Netherlands for its financial support through the MaMaSe project. Furthermore, we would like to acknowledge the management teams of the conservancies in the Maasai Mara, their umbrella organization, the Maasai Mara Wildlife Conservancies Association (MMWCA), the Kenya Wildlife Conservancies Association (KWCA), the Department of Resource Surveys and Remote Sensing (DRSRS), the Kenya Wildlife Service (KWS), the National Museums of Kenya – Botany section, SNV, the World Wildlife Fund (WWF), and Upande Inc.

References


Assessing the impacts of different initiatives on the rehabilitation of pastoral and silvopastoral ecosystems: Big Data oriented approach

Moukrim S.1,2, Lahssini S.3, Naggar M.2, Menzou K.2, Mharzi-Alaoui H.2, Labbaci A.4, Rhazi L.1

1 Mohammed V University in Rabat, Faculty of Sciences, Research center of plant and microbial biotechnologies, biodiverty and environment, Rabat, Morocco.
2 Waters and Forests Department, Rabat, Morocco.
3 National School of Forest Engineers, Salé, Morocco.
4 Ibn Zohr University, Agadir, Morocco.

Keywords: Forest Rangeland; Rehabilitation; Assessment; Big Data; GEE; Silvopastoral

Abstract
Through providing goods and ecosystem services, Moroccan forests underpin benefits to local communities and play a crucial role in rural area development. However, the legal framework recognizes people living near public forests the right to graze their domestic livestock. Over the years, the grazing pressure has been at levels far beyond the forestland’s carrying capacity throughout the country. Such pressure has been demonstrated as the main cause of forest cover loss and land degradation in Morocco and still threatening the sustainability of forests. To reduce the heavy grazing pressure on forest ecosystems and ensure their regeneration, several initiatives have been conducted, such as the Compensation for Forest areas Closed to Grazing (CFCG), initiated by the Moroccan forestry department. Several studies presented the socio-economic impact assessment of this mechanism, but its effectiveness for forest rangeland rehabilitation remains scarce and very spatially limited. To deal with this concern and assess vegetation dynamics through various spatial and temporal scales, parcels managed by CFCG and others within similar conditions were chosen. Time series of remotely sensed spectral indices at each parcel was used for vegetation cover dynamics assessment. Google Earth Engine platform (GEE) was used as computing platform.

As a result, the spectral indices trends show a long-lasting degradation tendency in areas planted without compensation than those managed under oversight by CFCG. Such results were also verified using aerial images covering the analyzed parcels. In conclusion, within comparable conditions, CFCG improved vegetation cover trends. The use of the GEE Platform simplified the process of treatment of remotely sensed imagery and made it easy to assess the state of the vegetation and will be of great use in assessing the impacts of different programs and initiatives on the restoration of pastoral and silvopastoral ecosystems.

Introduction
Moroccan rangelands, holding a diversity of species and providing ecosystem services for communities, play a crucial role in rural development. Indeed, provided services include supporting, provisioning, regulating and cultural services important for human wellbeing. Moroccan Rangelands cover about 53 million ha. Depending on land tenure status and dominant vegetation, rangelands are classified into: i- natural vegetation within forest rangeland domain that cover 9 million ha, ii- natural vegetation in common land covering 12 million ha, iii- private cropland used as rangeland after harvesting and during fallow 10 million ha, and 21 million ha of badlands owned by the state and used as rangelands and contribute for almost a third of the national livestock fodder (Narjisse, 2006). A wide majority of the rural population rely directly or indirectly on livestock revenues.

In the past, natural rangelands in Morocco were managed sustainably. Local populations developed ingenious sustainable systems of using and managing scarce natural resources. Such systems reconcile social needs and environmental requirements to maintain renewable resources
and biodiversity (Alkemade et al., 2013). Over the years, these rangelands knew an advanced degradation, and the grazing pressure is at levels far beyond the rangeland’s carrying capacity throughout the country. Efforts have been made to launch initiatives and pilot projects for rangelands restoration and rehabilitation and of their sustainable management to remedy degradation trends. However, even if socio-economic impact assessment of those initiatives was conducted within several studies, their effectiveness for rangeland rehabilitation remains scarce. This kind of assessment has traditionally been difficult and costly, even spatially limited and impossible at a large scale or with different temporal resolutions.

To deal with those concerns and to assess the effectiveness and the impacts of different initiatives on pastoral and silvopastoral ecosystems through various spatial and temporal scales, we prospect within this study the use of GEE- Google Earth Engine (Bey et al., 2016), as planetary-scale cloud-based geospatial analysis platform, for processing remotely sensed images and then to derive vegetation indices which are correlated to vegetation cover dynamics and productivity and providing a measure that indicates the vigour of vegetation (Reed et al., 1994).

Materials and Methods

Study Site

Morocco is located at the northwestern corner of the African continent, between the Mediterranean Sea in the north and the Atlantic Ocean in the west. The geographical location of Morocco and its topography explain its wide diversity of ecological conditions. Natural rangelands are present in different Moroccan terrestrial ecosystems. The combination of changes in demography, climate, technology, economy, politics, and cultural or religious beliefs (Dominguez et al., 2010) has intensified a variety of natural resource crises, mainly excessive livestock grazing and frequent unsustainable use, which has become a large practice affecting the different region, and which later made livestock grazing the greatest threat to the health and sustainability of Morocco’s rangelands.

Several initiatives have been conducted to rehabilitate these areas to reduce the heavy grazing pressure on rangelands and ensure their sustainability. For example, programs of establishing pastoral improvement perimeters and programs of compensation for forest areas closed to grazing (referred here as CFCG) were initiated by the Moroccan Forestry Department. The CFCG aims to support forest and forest rangeland rehabilitation programs by giving financial incentives to the neighbouring inhabitants, called users. They were organized in associations and agreed to respect grazing closure in the intervention sites.

In this study, to assess the impacts of those initiatives and others on the rehabilitation of rangeland ecosystems at a large scale, we evaluate the potential of medium-resolution satellite imagery for this purpose. The approach utilizes Google Earth Engine, a state-of-the-art cloud computing platform, which is a technology that can rapidly deliver information derived from remotely sensed imagery in near-real-time. GEE was used for data collection and treatment (Bey et al., 2016). In addition, it helps to map vegetation vigour using vegetation index, especially the Normalized Difference Vegetation Index (NDVI), which is correlated directly to vegetation productivity (Reed et al., 1994).

Results

NDVI changes indicating the relative trends of the health/vigour/cover of vegetation in different sample plots were analyzed within plots concerned by CFCG and compared to that of control sample plots that remain. The results are shown in Figure 1. NDVI trends over time show a degradation tendency in areas planted without community organizations and compensation compared to those concerned by the mechanism of compensation (Figure 1). Photos in Figure 2, showing the vigour and the state of vegetation before and after implementing the mechanism, illustrate the trends within some sample plots. NDVI change trends analysis revealed that the compensation mechanism enhanced the success of forest-rangeland rehabilitation activities. Such success is crucial and is a biological prerequisite to ensure land sustainability. Also, the field observations and discussions with key actors and forest-rangeland managers revealed that the CFCG mechanism had positive impacts on restoring plant species composition, diversity, biomass, cover and structure of herbaceous and woody components, improving soil nutrient status, leading to a reduction in erosion. These findings agree with literature focusing on improving canopy cover in grazing exclosures (Hammi et al., 2010).
The GEE processing platform facilitated and simplified the process of geo-synchronising, visualising, and imagery of varying spatial and temporal resolutions from different imagery sources to produce maps and statistics for our different sample plots. GEE appears as the Geo Big Data analysis platform as more functional from an operational perspective, powerful and at the same time easy to use.

Conclusions/Implications
From a perspective and to overcome managers’ lack of technical skills or computing infrastructure capacities, we can prototype and develop a web-based application to automate massive amounts of remote sensing data processing by combining medium spatial resolution imagery with the computation power of Google Earth Engine. Such a solution must help managers monitor vegetation response to rehabilitation initiatives at a large scale.

The framework will be based on repeated measurements of several vegetation indexes at various times over time-period. Measurements will be taken for each time step at locations concerned by a program of rehabilitation or restoration (Before and after the intervention). Also, measures will be taken at similar other locations in regards to the ecological condition and which is not concerned by the program of rehabilitation.

Acknowledgements
We thank Moroccan forest and rangeland managers for providing valuable field assistance and support.
References


CONCURRENT SESSION 3

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Sustainable Land Use
Grasses and Ruminants That Will Help Save Space Ship Earth

Craig, A.M. 1; Blythe, L.L. 2

1 Willamette Toxicology Consulting; 2 College of Veterinary Medicine, Oregon State University

Key words: cool season grasses; bioremediation; munitions

Abstract
For the last twenty years, it has been known that grasses are capable of extracting toxins from the soil. More recently, it has been shown that microorganisms from ruminants, especially sheep, can biodegrade certain toxins in plants and soil, including munition residues. The combination of these two processes act as an agricultural means to clear toxins and munitions from land has been termed Phyto-Ruminal-Bioremediation by the United States Department of Agriculture (USDA) as illustrated in the discussion below. As an example, plants containing toxins such as pyrrolizidine alkaloids can be cleared from pastures using sheep and their ruminant microorganisms. Use of grasslands and certain grasses is also being used to clean up other toxins such as munitions in areas where residues of explosives have been left following wars, especially in the middle east. This includes Kuwait’s Desert Storm, as well as, Egypt’s battles in World War II. It has been documented that when a bomb explodes or a cannon fires, 15% of the munitions is non-oxidized and lies as a toxic residue on the soil. This is true even after many years pass by, i.e. nearly 80 years. The use of the Phyto-Ruminal-Bioremediation technology has the ability to revitalize “war-torn” areas into sustainable pastures for animal production and food production for human populations. The presentation will establish the scientific basis for this new agricultural based technology, Phyto-Ruminal-Bioremediation. This scientific approach to clean-up pollutants is a new paradigm for bioremediation. Grasses and ruminates have the potential to make this world a better place.

Introduction
The impetus for this new paradigm had simple beginnings. In veterinary medicine, it was known that sheep were resistant to the pyrrolizidine alkaloids (PAs) that are contained in certain toxic weeds such as tansy ragwort (Senecio jacobaea). With these toxins, while sheep were resistant, cattle and horses were not. When cattle and horses repeatedly ate this common weed in the pastures, they developed and died from a chronic liver disease. This left the question of why were sheep resistant and cattle and horses not, especially cattle who are also ruminants like the sheep. Initial thoughts by some scientists were that the liver in sheep was able to detoxify the PAs while the liver in cattle could not. Our lab discovered that the ruminal microbes of sheep were different and able to detoxify the PAs before the alkaloids went systemic in the animal. (Wachenheim et al., 1992; Craig et al., 1992). So a series of experiments at Oregon State University and USDA were conducted in-vitro and in-vivo with sheep and cattle. The experiments were conducted to determine the degree of protection from the ruminal microbes when the animals were either (1) fed plant material or (2) when extracted PAs were infused into the liver (Hovermale et al., 2002; Duringer et al., 2004). These experiments were able to determine that the sheep ruminal organisms were the protective entity (Ivey et al., 2005).

These conclusions led us to an insight that possibly ruminal microbes could degrade other nitrogenous compounds such as found in munitions. Moveover, plant material that existed 65 million years ago is now oil. Could both of these substances and their molecules be degraded by ruminal microbes? This paper will concentrate on munitions. This led to a series of three types of experiments to determine: first, could plant material bring up munitions from the contaminated soil; second, could sheep ruminal microbes either in-vitro or in-vivo, biodegrade these nitrogen containing munitions into non-toxic molecules and, finally, could sheep be fed radiolabeled TNT (2,4,6-trinitrotoluene) and break it down into non-toxic moieties with no harm to the sheep (Smith et al., 2008).

The following experiments were conducted primarily at the Endophyte Testing Laboratory at OSU in Corvallis Oregon and USDA to develop
“proof of concept”.

Methods and Results.

Experiments 1. Determination that grasses could incorporate munitions and munitions residues in vitro using radiolabeled TNT.

A study was undertaken to determine if three types of grass could bring up and incorporate radiolabeled TNT in their leaves. The grass species were tall fescue (*Festuca arundinacea*, “SR4600”), perennial ryegrass (*Lolium perenne*, “Century”) and orchard grass (*Dactylis glomerate*). Chehalis Silt loam was placed in 6 inch pots. The pots had C$^{14}$ TNT added to the soil at 2.8 uCi/mg and 10 mg/ml cold TNT was dripped into the soil. Four pots of each species were seeded with the individual grass species and placed in a greenhouse to grow. Clippings of the grasses were taken at 63, 181 and 369 days after planting. Figure 1a. Autoradiography of the dried leaves were taken plus using HPLC analyses to measure the TNT content. Figure 1b. All three cool season grasses were able to extract TNT from the soil with variations between grasses. This showed that grasses can effectively extract TNT from the soil (Duringer et al., 2010).

Figure 1a. Grasses grow with thick root mass down to 1 meter depth

Figure 1b. Left side is a photo of the grasses, Right side is autoradiography of same grass showing radiolabeled TNT content

Experiments 2. In-vitro use of ruminal microbes to detoxify TNT, RDX,HMX, TNT (2,4,6, trinitrotoluene). The initial study was an in-vitro investigating the ability of ruminal microbes from sheep to biodegrade TNT (Fleischmann et al., 2004). Using an artificial rumen, sheep ruminal microbes were collected and incubated with TNT. Figure 2 shows that the initial TNT spike was totally degraded by one hour and only TNT metabolites were remaining. By four hours of incubation, the TNT metabolites were degraded into non-toxic moieties. Sterilized rumen fluid did not result in this TNT metabolism (Fleischmann et al., 2004; Craig et al., 2006; Perumbakkam et al., 2011)

Figure 2: Graph of the time line of ruminal microbes degrading TNT under anaerobic conditions. Pasteurization of these microbes do not result in TNT degradation
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine). A series of in-vitro experiments with whole rumen fluid anaerobically incubated with RDX were conducted. In addition, 16s RNA based genomic extractions were analyzed to identify the responsible bacteria as well as their metabolism (Eaton et al., 2011; 2012; Perumbakkam et al., 2012). Next, genes were identified that degraded the RDX incubated with the sheep ruminal microbes (Gioriozzo et al., 2013) It should be noted that soil bacteria take several months to years to degrade RDX as well as TNT, whereas ruminal microbes degrade these compounds in hours (Li et al., 2014).

![Figure 3: RDX degradation](image)

**Figure 3:** RDX degrades when incubated with ruminal microbes under anaerobic conditions in 2 hours. Not shown is soil microbe degradation which takes years to break apart this molecule (Li et al.; 2014; Ryott et al., 2011)

HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocane). Correspondingly, the third high explosive nitroamine was investigated for rumen fluid degradation. HMX was incubated with whole rumen fluid similar to the experiments above with TNT and RDX. Pasturized rumen fluid did not degrade HMX whereas live ruminal microbes anaerobically degraded HMX to non-toxic metabolites and small molecules within hours. Moreover, quantitative sequencing for the classification of 16s rRNA of HMX clones was done. (Perumbakkam et al., 2012; Eaton et al., 2014)

**Experiment 3.** Feeding sheep with radiolabeled TNT to in-vivo determine the breakdown products by the sheep ruminal microbes. The distribution of the radiolabel, and the health of the sheep during this process.

Sheep were dosed with 35.5 mg dietary non-labelled TNT for 21 consecutive days. This was an appropriate amount of TNT that would be in plants grown on TNT from contaminated soil. On day 22, a total of 1689 uCi 14C TNT was then administered to the sheep in an oral bolus. The purpose of these studies was to determine the mass balance of the radiolabeled toluene molecules. Extensive extraction protocols were used to measure the TNT, toluene, and the radiolabeled 14C TNT. There was a complete mass balance calculated and none of the toluene molecules were present. The radiolabel was only found in short chain carbon molecules. In conclusion, approximate 10% of the carbon molecules were found in the body tissues, 17% was in the urine, and 73% in the feces. It must be noted that no clinical signs were ever observed in the sheep with this treatment (Smith et al., 2008).

**Discussion**

These studies supports an agricultural solution to munition remediation. It is documented that munitions, ie bombs or cannons, when they explode, leave a 10% to 15% residue on the soil. This residue is toxic to animals and humans. These studies demonstrate that cool season grasses are able to absorb and extract TNT from this contaminated soil. Ruminal microbes from grazing sheep complete the reduction as well as break the covalent binding of TNT in the explosive-residue-laden plant material. Ultimately, this results in uncontaminated soil suitable for producing safe feed for animals as well as safe feed for humans.

**Acknowledgements**

USDA grants; Office of Naval Research Grants; Tyndall Air Force; Oregon State University AgExperiment Station.

**References**


GróLind – Sustainable Land use Based on Ecological Knowledge

Marteinsdóttir, B.1; Pórarinsdóttir E.F.1; Halldórsson G.1; Stefánsson J.H.1; Pórsson J.1; Svavarsdóttir K.1; Finnsdóttir R.1; Jónsdóttir S.1.

1 Soil Conservation Service of Iceland, Gunnarholt, 851 Hella, Iceland

Key words: monitoring; rangelands; sheep grazing; sustainable land management

Abstract
The highlands of Iceland play an important role as summer rangelands for sheep. However, large areas are badly degraded, and this practice’s sustainability has been questioned. To achieve sustainable land management, it is necessary to obtain data on ecosystem changes over time and ensure that land users and policymakers use the results in their management plans.

Currently, Iceland’s first long-term national vegetation and soil monitoring programme (GróLind) is being developed. The programme is based on an agreement between the Icelandic National Associations of Sheep Farmers, the Farmers Association of Iceland, the Ministry of Industries and Innovation, and the Soil Conservation Service of Iceland. The overall objective is to use ecological data to promote, in collaboration with stakeholders, sustainable land management in Icelandic rangelands.

The focus is on monitoring variables linked to ecosystem function and structure to estimate rangeland conditions and detect changes over time. The programme uses an adaptive monitoring approach and focuses on vegetation, soils and land use. Data will be collected at different spatial scales. Satellite images provide data for the whole country, while drones and on-site ecosystem analyses by land users and specialists are used for obtaining higher resolution data. In addition, the programme will develop indicators of sustainable land use based on experiments, active ecosystem monitoring and other available information.

To ensure that GróLind meets its objectives, stakeholders are actively involved in all project steps. This includes regular meetings of stakeholders and their integral involvement in the monitoring programme and presentation of results.

Introduction
Most sheep graze the extensive rangeland commons in summer without shepherding in Iceland. This grazing system has traditionally been profitable, with high production at low cost to farmers who utilize the rangelands at no charge. However, a large part of these rangelands, especially in the highlands, consists of unstable, poorly vegetated and unproductive ecosystems (Marteinsdóttir et al., 2020), many of which are badly degraded (Arnalds et al., 2001). Thus, the sustainability of this grazing system has been questioned (Ross et al., 2016). Until now, the condition of these rangelands has not been regularly monitored, and only a few have studied the influence of this grazing practice on vegetation and soils in the rangelands (but see Marteinsdóttir et al., 2017). Furthermore, information on stocking rates, or even the size and extent of the rangelands, was not systematically gathered until 2020 (Stefánsson et al., 2020).

Iceland’s first national vegetation and soil monitoring programme was initiated in 2017 to promote sustainable grazing practices. The programme was given the acronym GróLind and is based on an agreement between the Icelandic National Associations of Sheep Farmers, the Farmers Association of Iceland, the Ministry of Industries and Innovation, and the Soil Conservation Service of Iceland. The programme is run by the Soil Conservation Service of Iceland and funded until 2026, but an independent interdisciplinary science committee oversees the programme.

In the programme, ecological data will estimate rangeland conditions and detect changes over time. Also, information on how the rangelands are
being used (e.g., sheep and other grazing animals) will be monitored. From data gathered and other resources, like experiments, indicators of sustainable land use will be developed. Here, we briefly describe the methods used for monitoring and what is being done to ensure that the data gathered will result in more sustainable land management.

**Soil and vegetation monitoring**

The monitoring is based on methods developed to monitor rangelands in the USA (Herrick *et al.*, 2005, Pellant *et al.*, 2018) and Australia (Tongway and Hindley 1995) and the protocol developed by The Conservation of Arctic Flora and Fauna (CAFF) for monitoring Arctic biodiversity (Christensen *et al.*, 2013). The focus is on monitoring indicators that are related to key ecosystem functions: 1) the capacity of the ecosystem to withstand soil erosion, 2) the hydrological function, and 3) nutrient cycling. In addition, the programme follows an adaptive monitoring approach, where the knowledge gained will be systematically used to improve the monitoring (Lindenmayer and Likens 2009, Ringold *et al.*, 1996).

The monitoring will be conducted at different spatial scales by both specialists and land users. A network of over 1000 randomly distributed monitoring points around the country (stratified random) is being set out. A 50 x 50 m plot is laid out at these points where vegetation cover, soil erosion, vegetation stratification, and soil texture are estimated. Two 50 m long belt transects are laid within the plot, and bare ground, vegetation cover, species richness, soil depth and vegetation height are measured. Around 200 points are measured each year by trained field teams, and measurement at each point will be repeated every five years. In addition, a citizen science monitoring programme is being initiated so that land users and the public can set up monitoring points with the help of a mobile app. This programme is under development and being tested. The data collected will be a part of the monitoring network in GróLind, but land users will also be able to follow the progress of their sites from year to year.

In addition to monitoring data obtained in the GróLind project, vegetation and soil monitoring data will be gathered from other projects in Iceland, both from the Soil Conservation Service of Iceland and other governmental institutes. These data will then be combined with drone data and satellite images to estimate the country’s rangeland conditions.

**Monitoring land use**

To promote sustainable land use, information on annual stocking rates and the location and extent of the rangelands needs to be available. To obtain this information, GróLind mapped, in collaborators with stakeholders, the extent of the Icelandic rangelands for the first time in 2020 (Stefánsson *et al.*, 2020). That map showed that around 62% of Iceland is used as summer rangelands for sheep divided into over 1500 rangeland units (Fig.1). As of 2021, all farmers that use the rangelands need to register the number of sheep in each rangeland unit in a central database as part of their registration for agricultural subsidies. From that data, accurate annual stocking rates will be calculated and linked to data on the rangeland condition.

![Figure 1: Summer rangelands for sheep cover around 62% of Iceland (light brown).](image)

Icelandic rangelands are not homogenous but rather a mosaic of different vegetation types (Ottósson *et al.*, 2016). Therefore, it is important to understand how sheep use different vegetation types to predict...
the impact of grazing in an area. In 2018, a study was initiated in which around 100 sheep using ten different rangelands were equipped with GPS collars. The location of the sheep is tracked every 6 hours for the duration of the rangeland grazing period. First results based on data gathered over three summers indicate that how the sheep use the land is highly influenced by the condition of the land and available vegetation types. At the same time, the behaviour of different flocks and individuals is similar from year to year.

**Sustainable land use**

To ensure that GróLind meets its objective of promoting sustainable land management, stakeholders are actively involved in all project steps. Since the beginning, there have been regular stakeholder meetings, and stakeholders will also participate directly in the monitoring, as discussed above. Also, when major results are officially presented, all of the various associations and institutes that support the GróLind project are done jointly.

To ensure the scientific integrity of the project, the work is regularly reviewed by scientists outside the Soil Conservation Service and an inter-disciplinary committee assigned by the government. In addition, the project’s website provides detailed information on the methods used and their scientific background (www.grolind.is). All data and maps produced by the project will also be published there, and an interactive map viewer will be developed to assist rangeland managers in managing their land sustainably.

**Conclusion**

The project is still in its early phase, but now for the first time, stakeholders and scientists are working together to generate data that can be used for sustainable land management. In a country that is extensively used for sheep grazing and with a long history of land degradation, it is surprising how little has been done to monitor land conditions. However, it is not enough to monitor and gather reliable data. For a project like GróLind to work, the social-ecological system and policies will have to change. More and better data will make it easier to set evidence-based policies.

**Acknowledgements**

We want to thank all who have contributed to this programme, both within and outside the Soil Conservation Service of Iceland, especially the interdisciplinary committee behind the project. The project is funded through the agricultural framework agreement and the Soil Conservation Service of Iceland. In addition, the GPS sheep study was partially funded by the Framleiðnisjöður Landbúnaðarins.

---

**References**


Holistic planned grazing can improve vegetation attributes of the semi-arid communal rangelands of the Lowveld in the Eastern Cape, South Africa

*Mudiyiwa, S.M.; Beyene, S.T.; Mopipi, Kth

University of Fort Hare, Faculty of Science and Agriculture, Department of Livestock and Pasture, P/Bag X1314, Alice, 5700, South Africa
*Corresponding author

Key words: Holistic planned grazing, degradation, sustainability

Abstract
Most of South African rangelands face widespread degradation due in part to poor grazing management practices and development agents are encouraging communal livestock farmers to convert to holistic planned grazing (HPG) management as an alternative to conventional grazing. Holistic grazing is considered to decrease negative effects, and enhance rangeland vegetation, securing forage for livestock and wildlife and conserving environment. A study was therefore conducted to examine the effects of grazing management on botanical composition, species diversity and biomass yield in the semi-arid communal rangelands in the lowveld region of the Eastern Cape province, South Africa. We sampled three communal-HPG, and three communal-continuous grazing camps adjacent to two commercial-rotational farms. Each camp or farm was divided into three major landscape positions (upper, middle and lower slope). Two 100m transects were marked in each landscape to record vegetation data. A step point method was used to estimate grass species composition on 100 step points from each transect. Net primary aboveground biomass was estimated from two 1m$^2$ exclosures established in each landscape position. All standing live vegetation in one 0.25m$^2$ quadrat was harvested at 5 cm within each exclosure to determine dry matter. A total of 23 herbaceous species were identified in all study sites. *Eragrostis chloromelas* and *Aristida congesta* dominated in all grazing systems with more productive species such as *Themeda triandra* and *Digitaria eriantha* being more abundant at HPG compared to the continuous grazing lands. Mean values for biomass yield in the dry season was higher in HPG (261kg/ha) than continuous (109kg/ha). There were no significant differences (P>0.05) in net primary aboveground productivity, species diversity, richness and evenness although greater values were recorded for HPG than continuous grazing. The current study showed that holistic grazing can enhance vegetation conditions in communal degraded lands and improve rangeland productivity for sustainable livestock production.

Introduction
South African rangelands occupy more than 70% of the country’s total surface area (Snyman 2003; Moussa et al., 2009) with the majority facing widespread degradation (Kotze et al., 2013) due in part to poor grazing management practices. In the grassland ecosystems of South Africa, two livestock production based land use and management are widely recognized, namely communal-continuous or commercial-rotational grazing. The production systems differ in terms of available grazing resources, production objectives, management and use of the rangeland resources (Siyabulela et al., 2020). Since the last few decades, another land use practice known as Holistic Planned Grazing™ (HPG) has been introduced in both communal and commercial farms. The practice uses high stocking density to mimic nature and is purported to have positive long-term effects by restoring degraded rangelands and adapting to the impact of changing climate. Thereby having long-term positive effects on rangelands and the animals. Indeed, there are mixed views between farmers and scientists on the benefits of HPG over the conventional grazing methods (McIvor 2013). In South Africa, however, changes in the grass layer variables between the HPG and communal-continuous management have not been documented. The objectives of the study were therefore to investigate the species composition, diversity and above ground herbaceous yield under continuous...
and HPG at three landscape positions (upper, middle and lower) in the lowveld regions (Mceula communal lands) of the Eastern Cape province, South Africa. The findings from this study would be useful for farmers, development partners and decision makers in selecting grazing management practices that may improve rangeland conditions in this region.

Materials and Methods
The study was conducted in Mceula communal lands located in Enock Mgijima Local Municipality, characterised by dry highveld Sand Grassland and Valley Thicket. Three continuous and three HPG camps were selected for this study. Mceula has been practicing HPG since 2013 through the help of Olive Leaf Foundation to address degradation problems. Each camp was divided into three major landscape positions (upper, middle and lower). Two 100 m x 10 m permanent plots were established in each major landscape unit giving a total of 36 plots. In addition, two 1m x1m (1m²) grazing exclosures were fenced in each site for long-term monitoring and biomass estimation. The exclosures were erected before the onset of the growing season in August 2016. The plots were approximately 50 m apart. A step point method was used to estimate the composition of the herbaceous layer from 100-points observation per plot (Mentis 1981). Point observations one metre apart were made along two straight parallel lines (transects) 5m apart over the length of the plot. Data collection on grass species composition was carried between April-May 2017. Vegetation diversity was calculated using Shannon’s diversity index (Krebs 1989) while evenness was calculated using the formulae adopted by Teka et al., (2013). All herbaceous vegetation within each exclosure was harvested to a stubble height towards end of the growing season for aboveground biomass determination (ANPP). Standing vegetation outside the exclosure was also harvested from ten 0.5 m x 0.5 m (0.25m²) quadrates. The harvested materials were placed in paper bags and dried to constant weight at 75°C for 48 hours and weighed to determine the dry biomass yield. In the first year herbaceous biomass was harvested during the dry season (August) and in the second year, it was harvested towards the end of the growing season (March). Data were analysed using the Mixed Model procedure of SAS (2007) to test for the effects of grazing management and landscape position on biomass production, species composition, basal cover, diversity, richness and evenness. Mean separation was conducted using the PDIFF procedure of SAS (2007).

Results

Herbaceous layer
A total of 23 grass species were identified in all study sites of which 3 were annuals, 15 were long-lived perennials and 5 were short-lived perennials. Twenty-two percent of the total grasses were classified as highly palatable species, 30 % as moderately, 22 % as less desirable and 26 % as virtually unpalatable species. A species is referred to as dominant when the average frequency exceeds 12 % at least in one land use system and is considered common when its average frequency falls within >5-12 % (Siyabulela et al., 2020). Based on these definitions the following grass species were regarded as common or dominant: Aristida congesta, Chloris virgata, Cynodon in incomplete, Digitaria eriantha, Eragrostis chloromelas, Heteropogon contortus, Microchloro caffra, Panicum stapfianum, Sporobolus stapfianus, Themeda triandra, Tragus koelerioides, Urochloa panicoides and Forb spp.

Composition of common and dominant herbaceous species
The abundance of Aristida congesta, was significantly affected by land management (P=0.003) but without significant effect of landscape position and interaction of the two factors. Accordingly, continuous grazing had greater abundance of Aristida congesta than HPG, whereas with regard to landscape, lower slopes had greater abundance in all land management (mean:28 %) than the middle (15 %) and upper slopes (18 %). Similarly, both land management (P = 0.05) and landscape (P = 0.02) affected the occurrence of C. incompletes being highest in continuous grazing and in the upper slope (mean: 15 %) compared to the middle (mean: 5 %) and lower slope (7 %). For D. eriantha, there was significant difference (P < 0.05) between land management systems, and a presence of land management x landscape interaction effect (P = 0.03). The statistical difference between land management was limited only to the lower slope being higher in HPG (mean: 8.0 %) than continuous grazing (mean: 4.2 %). The proportion of E. chloromelas was significantly lowest (P < 0.05) in continuous grazing and in the upper slope of all management systems (mean: 12 %) compared to the other landscape positions (mean: 21 %). Both H. contortus and T. triandra were recorded only in HPG while Microchloro caffra and Tragus koelerioides were recorded only in the communal grazing systems. The abundance of S. stapfianus was significantly greater (P <0.05) in HPG and highest (P < 0.05) in the upper slope of
the continuous grazing land use. The occurrence of *U. panicoides* varied between land management systems (*P* = 0.01) and these significant variations were limited to the lower and middle slopes of the continuous grazing system.

**Life form, palatability and ecological groups**

The proportion of annual and short-lived perennial grasses was significantly lowest (*P* < 0.01) in HPG land use. In all land use, the abundance of short-lived perennial grasses was significantly (*P* = 0.05) greatest in the upper slopes (mean: 24 %) and lowest (mean: 16 %) in the lower slopes. Long-lived perennial grasses had lowest (*P* < 0.0001) abundance in the continuous grazing land use system. Highly and virtually unpalatable species were more abundant (*P* < 0.05) in the HPG than continuous grazing camps, whereas moderately (*P* = 0.01) and less palatable (*P* = 0.06) species were more copious in the continuous grazing camps. As for ecological groups, Increaser I, Ila and invader species were recorded only in HPG camps. Increaser Iib and Iic species occurred more abundantly in the continuous grazing camps than HPG camps.

**Species richness, diversity and evenness**

Shannon’s diversity index, species richness and evenness were not affected (*P* > 0.05) by grazing management systems but slightly greater species richness value was recorded in HPG (9.8) than the continuous (8.9) grazing systems. Landscape positions showed a significant effect on diversity, being greater in the middle than the lower and upper slope positions of all camps. Landscape position also showed a significant effect on species richness (*P* < 0.01), but this interacted significantly with land management systems showing greatest value in the middle or upper slopes than the lower slopes only in HPG camps. Management x slope interaction affected (*P* < 0.05) species richness.

**Herbaceous biomass yield**

Mean values for available grass dry matter (DM) yield showed a significant (*P* < 0.0001) order of: CCHPG (261 kg ha-1) > CC (109 kg ha-1). Landscape position significantly interact with land management to influence the available DM yield. Middle slope recorded the highest available grass DM yield in HPG whereas in the continuous grazing camps, both middle and upper slopes had higher DM yield than lower slope. Annual net primary production of grass was not significantly affected by land management and landscape position.

**Discussion [Conclusions/Implications]**

**Herbaceous species composition**

The significantly greater abundance of increaser species in the communal rangeland especially under continuous grazing land use including *A. congesta*, *C. dactylon*, *C. virgata*, *E. chloromeras*, *H. contortus*, and *U. panicoides*, supports rangeland with poor veld condition which is overgrazed and is degrading (Smet and Ward 2005; Kgosikoma et al., 2015) justifying the introduction of HPG as a restoration measure to part of the rangeland. *A. congesta* and *T. berteronianus* have been shown to increase under heavy grazing (Abule et al., 2005). *Aristida* and *Chloris* spp. are grass species known to have poor forage value (Van Oudtshoorn 1999), good self-seeding ability, drought tolerance and spreading capacity (Jawuoro et al., 2017) hence their abundance. The greater occurrence of annuals including forbs in continuous grazing land than HPG could be an indication that palatable perennial grasses were replaced with annual grasses on grazing land which was subjected to higher grazing pressure. This study indicates high proportions of highly palatable and productive grasses in HPG land-use, an observation also made by Peel and Stalmans (2018) in their study in Zimbabwe. The high occurrence of *D. eriantha* in all grazing systems was unexpected. *Cynodon* spp. was present in continuous land use only. This agrees with the observation that in the Grassland Biome of South Africa, it is the key species in rangeland that is severely overgrazed. *Heteropogon contortus* a desirable species was common in HPG land use on patches of rocky soils. Continuous grazing had lower species richness than HPG which may reflect a positive outcome of the implementation of HPG. Given that HPG has been in place for a few years the results are striking. The relatively rapid response suggest that this communal rangeland is fairly resilient, and can quickly recover when subjected to appropriate grazing management practices. A similar observation was made by Odadi et al., (2017) in Kenya. Moreover, these improvements were evident despite higher stocking rates in HPG, suggesting that the benefits of planned grazing can outweigh any undesirable effects of increased stocking rate. Higher plant diversity in areas under HPG could be partly attributed to more even distribution of grazing pressure and reduced forage selectivity by concentrated livestock herds. The higher dry season grass DM yield in holistic managed camps than in continuous grazing camps may be attributed to longer forage recovery time under HPG. In continuous grazing animals have
unrestricted access to the whole range and this exposes plants to more frequent defoliation which can be harmful to productivity especially during the growing season. The animals continue to graze until forage becomes inadequate to sustain them. The combination of continuous grazing, higher stocking rates and grazing intensities put pressure on the grazing lands, resulting in the reduced production capacity of forages. Heavy grazing by goats and sheep also maintained the rangeland vegetation at low levels and can limit primary productivity. Greater dry season biomass yields observed in the middle and upper slopes than lower slopes may be attributed to animals aggregating on the lower lying areas close to watering points and also that low lying areas usually have better forage due to higher soil moisture and nutrient content (Alemayehu et al., 2013; Zhao et al., 2019). Grazing management systems have great ecological importance as they affect the productivity of rangelands. The study demonstrated that, if given enough attention, HPG can enhance vegetation conditions in communal degraded lands and improve rangeland productivity for sustainable livestock production.

Acknowledgements
We express our appreciation to the communal people of Mceula for their support in this research.

References


Indian Forage Scenario – Region wise availability and deficit


1ICAR- Indian Grassland and Fodder Research Institute, Jhansi- 284003

*Corresponding Author email: royak333@rediffmail.com; royak333@gmail.com

Keywords: Fodder deficit; cultivated fodder; rangeland; fodder conservation; grassland

Abstract
In India, rapid urbanisation, changing food habits and higher purchasing power have increased the demand for animal-based food products. Therefore, proper feeding strategies using nutritious green fodder are key to increasing livestock production and productivity economically and sustainably. Three major fodder sources are crop residues, cultivated fodder from arable land (irrigated and rainfed) and fodder from common property resources like forests, permanent pastures, grazing lands, cultivated wasteland, fallow lands etc.

We estimated the green and dry fodder availability vis-à-vis demand and emerging deficit/surplus situation based on the livestock census. The state-wise livestock population for Cattle, Buffaloes, Goat, Sheep, Yak and Mithun were taken into account, and the requirement for green, dry forage and animal feed concentrate was worked out considering age milking or non-milking state, gender, working nature, feeding practices etc. The availability of green forages was estimated based on cultivated area under forage, cropping intensity, productivity etc., green fodder from fallow land, wasteland, forest fringe areas, social forestry, pasture land. For dry fodder, availability of crop residue for fodder was calculated based on the major utilisable cereals, pulses and oilseed crops, harvest index, production, and utilisation pattern. In addition, the availability of dry forages from forest, wasteland, fallow land and cultivated field after harvest available for grazing was considered. On all India basis, there is an overall deficit of nearly 11 % in green fodder availability and 23 % in dry fodder availability.

Various strategies are proposed to meet the deficit scenario, including a national programme in mission mode for accelerating production; grassland and grazing policy; rejuvenation of degraded pastures; targeted research and extension programme; entrepreneurship in the commercial venture of fodder production and utilisation.

Introduction
India, with only 2.29% of the land area of the world, is supporting more than 17% of the world human population and 10.5% of livestock (more than 530 million heads), thereby creating tough competition for land, water and other resources (Roy et al. 2019b).

The livestock productivity in India is lower than the developed countries like the USA, Israel, Europe, etc. Non-availability of adequate feed resources is one of the main limiting factors contributing to low productivity. Various attempts have been made in estimating green and dry fodder demand and supply at the national level. But these studies have assumed that the gap between availability and nutritional requirement is between actual consumption and requirement. However, these assumptions need to be reconsidered with better logical assumptions and the available supportive data.

The livestock productivity in milk yield per lactation is low compared to countries like the USA, UK, Israel, etc. the major reasons are deficiency of feed and fodder, health, breed and improper management. Around 80% of the livestock are with marginal, small and medium holdings farmers under rainfed situations, whereas small ruminants are mostly reared under nomadic (30%) and sedentary (70%) systems. There are nearly thirty pastoral communities in India located particularly in the northern and western parts of the country (Roy and Singh, 2013).
In the present study, the state-wise green and dry fodder availability was estimated using both primary and secondary data vis-a-vis demand from various categories of ruminants and emerging deficit/surplus scenarios. In addition, the factors like agro-climatic zone, land use pattern, rainfall pattern, major crops and availability of crop residue, etc., were considered. In addition, data from various publications have been taken to estimate the dry forage or crop residue availability (Agricultural Research databook 2018).

**Livestock population and distribution**

The state-wise livestock population per livestock Census 2012 was considered for this study. The population of six ruminants, Cattle, Buffaloes, Goat, Sheep, Yak and Mithun, was converted into ACU (Adult Cattle Unit – 350 kg body weight) for calculation and estimation. The weight of different categories of animals based on age, sex, species, etc., was considered as per standard norms. It resulted in the total ACU being approximately 232 million for around 500 million livestock numbers.

Out of a total cattle population, 151 million were indigenous, and nearly 40 million were exotic. In Punjab and Haryana, the leader in milk production, exotic cattle outnumber indigenous. In other small states, exotic cattle are more because of peri-urban dairies. Overall country scenario indicated that exotic cattle are 20.8% of the total cattle population. Most indigenous cattle are of a nondescriptive type and are generally low milk yielders. Uttar Pradesh accounted for more than 25% of the population for buffaloes, followed by Rajasthan, Andhra Pradesh–Telangana, and Gujarat. In Hills and NEH buffalo population is much less. Sheep were found to be predominant in undivided Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, J &K and Gujarat etc. The goats were recorded mainly in Rajasthan, UP, Bihar, WB etc. Small ruminants were fewer in Punjab and Haryana, while Mithun was reported from Arunachal Pradesh and Himachal Pradesh. Similarly, Yak was reported from Western Hills and NEH regions only.

** Estimates of Green and dry fodder requirement**

The total dry matter requirement of livestock was estimated and converted into green, dry and concentrate requirements based on various factors like exotic/indigenous breed, age, milking or non-milking state, gender, working nature, feeding practices, etc.

The total dry matter requirement assumed was 1.8% to 2.8% of body weight for cattle and buffaloes, 3.0 to 3.5% for sheep and goat, 1.8% for Yak and Mithun. Therefore, the feeding ration was estimated to be a combination of green fodder, dry matter, and concentrates in varying proportions ranging from 40 to 80% for crop residue, 10 to 30% for green fodder and 10 to 30% for concentrates.

For these six categories of ruminants, i.e., cattle, buffaloes, goat, sheep, yak and Mithun, the estimate for total green fodder, dry fodder, and concentrate requirements were 827.19, 426.11, 85.78 million tonnes, respectively.

**Estimates of green and dry fodder availability**

Estimating green fodder availability from arable land was done using data on the cultivated area under forage, cropping intensity, productivity, penetration of technologies, rainfed and irrigated conditions, etc. Availability of green fodder from non-arable lands like fallow land, wasteland, forest fringe areas, social forestry and pasture land was also estimated depending on soil, rainfall pattern, state of grassland etc. The total green fodder availability was worked out to be 734.2 million tonnes from various sources such as grazing land, pastures, forests, top feed etc., of which forage from cultivated land was 88.0%.

Availability of crop residue for fodder was calculated using the data available for the major cereals, pulses and oilseed crops, their harvest index, production, and utilisation pattern for each state. In addition, the availability of dry forages utilisable for grazing from forest, wasteland, fallow land, and cultivated fields after harvest was considered. Finally, assumptions for a different production level were made depending on the productivity estimate based on rainfall, soil type, and grassland status (Agricultural Research data Book. 2018; Roy et al., 2019b.)

**Demand – supply gap scenario**

An overall deficit of 11.24% in green fodder availability was estimated in India. Total green fodder availability was estimated to be 734.2 mt against a requirement of 827.19 mt. Similarly, dry fodder availability was estimated to be 326.4 mt against the requirement of 426.1 mt., making an overall deficit of 23.4%.

For concentrate, our study indicated a requirement of 85.78 million tonnes at the national level; however, the estimated annual availability of total concentrate feed is only 61 million tonnes (Anonymous, 2018) which makes a deficit of approximately 24.78 million tonnes or 28.9% of the demand.

**Future strategies**

Future strategies should focus on precise
estimation feeding to enhance livestock’s economic productivity to make the industry economically and ecologically sustainable and viable. A suitable region-based feeding model should be developed for different categories of livestock based on age, gender, status. This should consider profitability as well as productivity/health. A national programme in mission mode for accelerating production and effective utilisation should be implemented for enhancing the nutritious fodder availability around the year. Our grasslands demand rejuvenation and conservation for better output, and there should be a proper strategy for this. In India, overgrazing, demand for fodder, mining, industrial activities are the main factors responsible for the loss of grassland. However, scientific management and rejuvenation of grasslands can lead to enhanced biodiversity and sustainability of the ecosystem and higher productivity (Malaviya and Roy, 2021). The strategies to develop suitable varieties and improvement of forage grasses and legumes have been discussed in detail in several reviews (Roy et al., 2016, 2019a). Proper planning and execution are required for developing improved varieties and technologies for different agro-ecological conditions. Entrepreneurship development in various fodder-based products/post-harvest technologies should be prioritised. Post-harvest technologies like densified dry bales (for transportation of crop residue from surplus to deficit states) and hay/ silage making for commercial dairies should be promoted. As of now, fodder production in India is not a commercial enterprise, but increasing demand for fodder opens a new avenue for entrepreneurship in the production, processing and marketing of fodder and products for specialised livestock production.

Acknowledgements

Authors are thankful to ICAR-IGFRI for support

References


Pre- and Post-Degradation Management of Rangelands: Implications for Sustainable Management

Tuffa S.1; Treydte, A. C.2
1Oromia Agricultural Research Institute, P. O. Box 81265, Addis Ababa, Ethiopia
2Agroecology in the Tropics and Subtropics, University of Hohenheim, Germany
3Biodiversity Conservation & Ecosystem Management, School of Life Sciences, Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania

Key words: resilience; restoration; management; improvement

Abstract
Rangeland degradation directly affects livestock production, resulting in food insecurity and ecological instability. A shift in vegetation from grass to woody plants has severely affected cattle production in Ethiopian rangelands. Those grass species that are perceived by the pastoralists as highly palatable and desirable are currently decreasing in both quality and quantity. A reason for this decline has been claimed to be degradation owing to overgrazing and climate change. While appropriate management of livestock density in rangelands is essential for sustainable production and grassland ecosystem health, the management of dryland ecosystems is mired in controversy due to the complexity of the ecosystem. This region is categorized as a non-equilibrium environment, though at times it experiences equilibrium characteristics, which makes the management of the Borana rangelands highly complex. A better understanding of grass productivity and its controlling factors in modern savanna ecosystems could be a key to understanding the productivity of savannas and to predict responses to future climatic changes. The development of effective management strategies for responding to climatic variability is often impeded by the lack of a systematic framework for analyzing livestock stocking policies and management practices. Further, effective decision making requires an understanding of the important biotic and abiotic components of rangeland systems, such as the response of rangeland vegetation to environmental stressors: climatic change and herbivorous population dynamics. Previous vegetation studies of the Borana rangelands focused mainly on taxonomic descriptions and rangeland condition assessments. Reseeding of degraded rangelands is a potential management option in eastern African rangelands to enhance the resilience of rangelands. Therefore, it is high time to understand how the native perennial grass individuals respond to increased herbivory under higher drought frequency after reseeding.

Introduction
Resilience and sustainable use of rangelands depend on pre- and post-degradation management. Sustainable rangeland use can be achieved by maintaining its productivity. Herbivory and drought are the two main stressors (Acharya, Rasmussen, and Eriksen 2012; Baruch and Jackson 2005) grazing multispecies mixture reducing the primary production of rangelands (Fay et al., 2000) and hence, related ecosystem services. In semiarid rangelands, herbivore populations can be kept at their varying carrying capacity through encouraging animal harvesting when forage production decreases to avoid rangeland degradation as pre-degradation management. Degraded areas can also be restored through reseeding with appropriate local species to enhance rangeland resilience, particularly given the current and projected impacts of climate change to cope with the rapid disappearance of species and ecosystem services. However, it is unclear how grass species currently used in the reseeding respond to the combined effects of herbivory and drought and how grazing cattle populations change under the current and the predicted increasing drought frequency.

The Borana rangeland, Ethiopia, had been highly productive and an important forage resource for livestock. However, its productivity has been reducing as a result of degradation, mainly caused by recurrent drought, land-use change, livestock overgrazing and bush encroachment (Angassa 2002; Gemedo-Dalle, Maass, and Isselstein 2006c, 2006a, 2006b; Haile, Assen,
Reseeding as a post-degradation management strategy for the restoration of degraded rangelands and their ecosystem services has been urgently recommended. This is particularly urgent as in the face of the human population increase a high demand for meat as a protein source is expected (FAO 2003) and mitigation strategies to capture CO2 from the atmosphere (Cook, Ma and Brain 2013) in the face of climate change are needed. Rangeland restoration as post-degradation management through reseeding of palatable grass species can improve both structural and functional vegetation characteristics, which will also enhance ecosystem services. In Borana, particularly two grass species (C. ciliaris and C. gayana) are important for cattle productivity as they are highly palatable and native to the study area. These two species further have vast global coverage, highlighting their potential for post-degradation rangeland management.

As cattle have been referred to as the true "economic engine" of the system, emphasizing the sustainable productivity of cattle is a crucial aspect (Coppock et al., 2014). For pre-degradation management, we hence modeled cattle population dynamics under varying carrying capacity and stochastic environmental conditions, which has never been done before in the semi-arid Borana rangeland ecosystem. This region is categorized as non-equilibrium environment, though at times it experiences equilibrium (Desta and Coppock 2002), which makes the management of the Borana rangelands highly complex. We combined the two concepts, and readers may refer to other papers (Desta and Coppock 2002; Sasaki 2010; Vetter 2005) to understand how the two concepts integrate into a semi-arid ecosystem. Modeling cattle population dynamics is essential for capturing changes in population responses to climate change in a variable social and ecological environment at a large temporal scale.

The lifestyle of people in the pastoral environment is dictated by two major concepts. In the dryland ecosystem, the driving factor of primary production is the climate while in humid ecosystems, herbivory and anthropogenic activities drive primary production (Figure 1).

**Materials and Methods**

Responses of two dominant perennial grass species (Cenchrus ciliaris and Chloris gayana) frequently used in reseeding to simulated herbivory and rainfall regimes were assessed in pot and field plot experiments on young grasses. Further, we addressed how herbivory influences biomass allocation and C storage in mature tufts of these two native grass species under ambient rainfall conditions (for details see Tuffa et al., 2017, 2018).

Further, we developed and evaluated a novel Boran cattle population trajectory model integrating non-equilibrium and equilibrium concepts by building stochasticity into the model, allowing droughts to occur randomly within model runs in Berkeley Madonna software, with different long-term average drought frequencies scenarios (See also Tuffa and Treydte 2017 for detailed algorithm of the model).

**Results**

The responses of biomass and C storage showed contrasting results across grass age as well as species. Generally, the clipping/grazing strongly triggered the belowground biomass allocation and
enhanced C storage of C. ciliaris tufts while C. gayana tufts differed only slightly (Tuffa et al., 2017). In both mature grass species, however, clipping highly reduced aboveground biomass and C storage. In contrast, for the young grass seedlings, moderate and light clipping triggered regrowth and, hence, biomass and C storage in both above- and belowground parts. Meanwhile, reduced irrigation showed the same effect on biomass allocation and C storage in both study grass species. Lower irrigation highly reduced biomass and C in both above- and belowground parts (results are published and a reader may refer to Tuffa et al., 2017, 2018).

The model result indicated that the overall population size was highly sensitive to the sale of the juvenile as well as mature female cattle when drought hit the system (Tuffa and Treydte 2017).

Discussion

Our experiments established the first interactive effect of herbivory and rainfall on the biomass allocation and C storage of mature and young grasses in the semiarid Borana rangelands, Ethiopia. Clipping/grazing further highly enhanced the belowground biomass and carbon storage, boosting the ability of grass to compete for water and nutrients (Engel et al., 1998). The enhanced belowground biomass due to herbivory was also observed in Spain (Garcia-Pausas et al., 2011), Argentina (Larreguy, Carrera, and Bertiller 2014; Pucheta et al., 2004) and the Netherlands (Veen et al., 2014). This might be attributed to the reallocation of resources away from the site of damage into storage organs after herbivory which reduces the chance of resources being lost to herbivores (Gómez et al., 2010).

In contrast to mature grasses, the aboveground biomass and carbon storage in newly established study grasses was higher under moderate clipping compared to the control, which concurs with studies from the Netherlands (Veen et al., 2014), USA (Frank, Kuns, and Guido 2002) and in Mediterranean rangelands (Herrero-Jáuregui, Schmitz, and Pineda 2016). The enhanced aboveground biomass might be attributed to greater photosynthetic capacity in younger leaves after clipping compared to the unclipped control (Nowak and Caldwell 1984) and the overcompensation phenomenon (McNaughton 1983). Clipping further stimulated the belowground biomass of newly established grasses, which concurs with many studies (Helland 1998; Piñeiro et al., 2010; Pucheta et al., 2004; Smoliak, Dormaar, and Johnston 1972; Veen et al., 2014). Knowledge of these interacting factors is deemed essential for policymakers to develop a sound rangeland management policy that can enhance the C storage potential of degraded rangelands under climate change and, hence, the mitigation and adaptation strategies through improved post-restoration of degraded areas.

The stochastic population modeling under varying carrying capacity in the face of increasing drought scenarios indicated the livelihood challenges ahead for the pastoral community. For sustainable use of the rangeland resources, cattle populations must be limited timely and grass productivity must be enhanced as pre-degradation management of rangelands. Management should focus on lowering cattle herd crashes through the increasing sale of mature males that increases feed availability to females during drought years in the Borana Rangelands as well as enhancing the resilience capacity of rangelands through maintaining healthy conditions and restoring degraded areas (Sternberg et al., 2000; Tuffa and Treydte 2017). Further, drought early-warning systems and market information must be strengthened so that pre-planned selling can be realized for the fair and sustainable use of the animal resource. Pastoralists would benefit from this approach as they could sell their animals before drought wipes out their cattle in huge numbers. The results of this study can be used by policymakers to develop an appropriate strategy that helps the pastoral community to be proactive in coping with drought by reducing its impacts on the cattle population.

Acknowledgements

We duly thank the Dr. Hermann Eiselen Research Grant from the Foundation Fiat Panis to undertake the field research.
References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forage evaluation and agronomy
Induction of tetraploid ruzigrass (*Brachiaria ruziziensis*) by colchicine and possibility of using seed weight as screening method

Poungkaew, R¹; Mangpung, Y²; Arananant, J³; Chuchuay, P⁴; Thaikua, S⁵; Chanpeng, P⁶

¹Nakhonratchasima Animal Nutrition Research and Development Center;  
²Nakhonratchasima Animal Nutrition Research and Development Center;  
³Bureau of Animal Nutrition Development, Department of Livestock Development,  
⁴Nakhonratchasima Animal Nutrition Research and Development Center;  
⁵Bureau of Animal Nutrition Development, Department of Livestock Development,  
⁶Pichit Animal Nutrition Research and Development Center

**Key words:** Brachiaria breeding, polyploidy induction, thousand seed weight

**Abstract**

Tetraploid ruzigrass (*Brachiaria ruziziensis*) have been obtained by colchicine treatment of in vitro apical meristems and embryogenic calli. The colchicine treatment consisted of culturing apical meristem on MS basal medium containing 6.0 mg L⁻¹ 6-benzylaminopurine (BAP) and 0.05-0.20% colchicine for 8, 14, 20 and 26 h. After being treated by colchicine, apical meristems were transferred onto the former medium without colchicine for four weeks. Surviving apical meristems were induced multiple roots on MS basal medium containing 2.0 mg L⁻¹ BAP. The ploidy level of plants after colchicine treatment was determined by flow cytometry. Apical meristems treated with 0.05% colchicine for 26 h. was identified as the optimum treatment and resulted in the highest frequency (13.3%) of tetraploid plants among the treatments tested on apical meristems. Embryogenic calli were induced on MS basal medium supplemented with 5.0 mg L⁻¹ 2,4-dichlorophenoxy acetic acid (2,4-D), 1.0 g L⁻¹ casein hydrolysate, 0.5 mg L⁻¹ kinetin and 5% coconut water. The colchicine treatment consisted of culturing embryogenic calli on MS basal medium containing 1.0 mg L⁻¹ kinetin, 0.1 mg L⁻¹ 1-napthaleneacetic acid (NAA) and 0.05-0.20% colchicine for 8, 14, 20 and 26 h. After being treated by colchicine, embryogenic calli were transferred onto the former medium without colchicine for four weeks. Shoots from embryogenic calli survived were induced multiple roots on MS basal medium containing 2.0 mg L⁻¹ BAP. Two tetraploid plants were obtained from embryogenic calli treated with 0.10% colchicine for 14 h and 0.15% colchicine for 26 h. A total of 16 tetraploid genotypes were clonally propagated and grew in the field, with one (1) diploid genotype as the control. It was found that the mean ± standard deviation of thousand seed weight (TSW) of all genotypes, tetraploid genotypes were 8.119 ±1.36 and 8.239 ±1.30 g, respectively, whereas TSW of diploid one was 6.209 g.

**Introduction**

One of the main pastures in Thailand is ruzigrass, primarily because of its high seed yields and nutritive value. However, although the potential of ruzigrass for increasing pasture and animal productivity is well documented, it is unable to adapt to grow in a long duration of drought, which causes forage crop lacking in the dry season. Therefore, ruzigrass breeding for increased yield in the dry season will benefit Thai livestock farmers.

The genus of *Brachiaria* mainly consists of tetraploid (2n = 4x = 36) and apomictic species such as *B. decumbens* and *B. brizantha*. Sexuality is found in diploid species (2n = 2x = 18) such as *B. ruziziensis* (Valle et al., 1994). One of the limitations of *Brachiaria* breeding is the ploidy difference between sexual and apomictic plants, which prevents crossings, generates a small number of hybrids, and causes sterility (Valle et al., 2004). To overcome this problem, a promising strategy is the artificial tetraploidisation of the diploid and sexual species *B. ruziziensis* and the subsequent hybridisation with tetraploid and apomictic genotypes of *B. brizantha* and *B. decumbens* (Ishigaki et al., 2009). Antimitotic substances, such as colchicine, an alkaloid widely used in forage species, are used in the induction of polyploidy (Pereira et al., 2012). Several duplication studies have been conducted on *B. ruziziensis*, including seeds germinated...
(Swenne et al., 1981; Ishigaki et al., 2009; Timbo et al., 2014) and multiple-shoot clumps (Ishigaki et al., 2009). However, Thailand had no tetraploid ruzigrass yet, causing Brachiaria hybridisation breeding delay.

Methods and Study Site

Embryogenic calli formation

Lemmas and paleas were removed from spikelets of diploid ruzigrass, and seeds were surface-sterilised in 10% and 5% (v/v) Chlorox (Clorox = 6% sodium hypochloride) for 5 and 10 min, respectively. Followed by three rinses with sterile water. Seeds were germinated on MS solid medium (Murashige and Skoog, 1986) supplemented with 0.5 mg L-1 2,4-D and 2.0 mg L-1 BAP at 25°C under a 16-h light condition for 1 week. Cultured apical meristems on MS solid medium supplemented with 5 mg L-1 2,4-D, 1 g L-1 casein hydrolysate, 0.5 mg L-1 kinetin and 5% coconut water at 25°C in the dark for 2 weeks and transferred to a 16-h light condition for 2 weeks. Increasing embryogenic calli by cultured on MS solid medium supplemented with 0.6 mg L-1 2,4-D and 0.1 mg L-1 kinetin at 25°C under a 16-h light condition for 4 weeks.

Colchicine treatment

Four hundred and eighty apical meristems were cultured on MS liquid medium supplemented with 6 mg L-1 BAP containing 0.05, 0.10, 0.15 and 0.2% colchicine for 8, 14, 20 and 26 h at 25°C in the dark and followed by three washings with sterile water. Following colchicine treatment, apical meristem was transferred to MS solid medium supplemented with 6 mg L-1 2,4-D and 0.1 mg L-1 kinetin at 25°C under a 16-h light condition for 30 days. Separated shoots from survival embryogenic calli to cultured on MS solid medium supplemented with 2 mg L-1 BAP at 25°C under a 16-h light condition for 6 weeks to induce root development. Transferred plantlets to the pots.

Flow cytometry

After 4 weeks, non colchicine-treated ruzigrass plant, colchicine treated ruzigrass plants derived from apical meristems, and embryogenic calli were proliferated shoots. Flow cytometry was performed to estimate the ploidy level of the plant according to the method of Atichart and Bunnang (2007). Non colchicine-treated ruzigrass plant was used as the internal standard. Approximately 0.5 g of young leaves tissue from non-colchicine treated ruzigrass plant, colchicine-treated ruzigrass plants derived from apical meristems and embryogenic calli were chopped with a sharp razor blade in a 55-mm Petri dish. The hypotonic buffer Cy stainR UV ploidy were added to the leaves tissue (1 mL of one step DAPI staining solution), then filtered through a 30 µm celltrics disposable filter. The samples were analysed the flow cytometry with Partec PAII. The number and size of guard cells were examined after staining the leaves’ epidermis with safanine solution. Chrolophyll content was determined following the method of Arnon (1959).

Thousand seed weight (TSW)

After estimating the ploidy level of ruzigrass, I planted non colchicine-treated ruzigrass (diploid) and various clones of tetraploid ruzigrass on the breeding plot (36 plants/breeding plot). Take the seed from each breeding plot to do thousand seed weight determination according to the method of International Rules for Seed Testing (2015). Eight pure seed replicates of 100 seeds must be drawn randomly from the submitted sample. Each replicate weight is recorded in grams to three decimal places, and the mean weight is determined from these 8 replicates. The mean weight of 100 seeds is then used to calculate the weight of 1000 seeds. Variance, standard deviation and coefficient of variance must be calculated using the formulas. If the coefficient of variation does not exceed 6.0 then the thousand seed weight is accepted. If the limit is exceeded, eight more replicates must be drawn and weighed.

Results

Effect of colchicine concentration and treatment duration on survival and chromosome duplication of the apical meristem
Induction tetraploid plants from *in vitro* apical meristems, the apical meristems were cultured on MS liquid medium supplemented with 6 mg L⁻¹ BAP containing 0.05, 0.10, 0.15 and 0.2% colchicine for 8, 14, 20 and 26 h. Only 32 individuals survived all treatment. The ploidy level was estimated by flow cytometry, and fourteen out of 32 plants were identified to be tetraploid. Four tetraploid plants were obtained from apical meristems treated with 0.05% colchicine for 26 h, the treatment resulting in the highest frequency (13.3%) among treatments (Table 1).

### Table 1: Effect of treatment duration and concentration of colchicine on survival and chromosome duplication of apical meristem of diploid ruzigrass

<table>
<thead>
<tr>
<th>Treatment duration (h)</th>
<th>Concentration (% w/v)</th>
<th>No. of explants treated</th>
<th>No. of explants survived (pieces/%)</th>
<th>Ploidy*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.05</td>
<td>30</td>
<td>6 (20.0)*</td>
<td>2X 1 3X 4X (10.0)* 0</td>
</tr>
<tr>
<td>8</td>
<td>0.10</td>
<td>30</td>
<td>5 (16.7)*</td>
<td>2 0 3 (10.0)* 0</td>
</tr>
<tr>
<td>8</td>
<td>0.15</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>1 0 0* 0</td>
</tr>
<tr>
<td>8</td>
<td>0.20</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>1 0 0* 0</td>
</tr>
<tr>
<td>14</td>
<td>0.05</td>
<td>30</td>
<td>4 (13.3)*</td>
<td>4 0 0* 0</td>
</tr>
<tr>
<td>14</td>
<td>0.10</td>
<td>30</td>
<td>0*</td>
<td>0 0 0* 0</td>
</tr>
<tr>
<td>14</td>
<td>0.15</td>
<td>30</td>
<td>0*</td>
<td>0 0 0* 0</td>
</tr>
<tr>
<td>14</td>
<td>0.20</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>0 0 1 (3.3)* 0</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
<td>30</td>
<td>3 (10.0)*</td>
<td>1 0 2 (6.7)* 0</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>0 0 1 (3.3)* 0</td>
</tr>
<tr>
<td>20</td>
<td>0.15</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>1 0 0* 0</td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
<td>30</td>
<td>0*</td>
<td>0 0 0* 0</td>
</tr>
<tr>
<td>26</td>
<td>0.05</td>
<td>30</td>
<td>7 (23.3)*</td>
<td>2 0 4 (13.3)* 1</td>
</tr>
<tr>
<td>26</td>
<td>0.10</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>1 0 0* 0</td>
</tr>
<tr>
<td>26</td>
<td>0.15</td>
<td>30</td>
<td>1 (3.3)*</td>
<td>1 0 0* 0</td>
</tr>
<tr>
<td>26</td>
<td>0.20</td>
<td>30</td>
<td>0*</td>
<td>0 0 0* 0</td>
</tr>
</tbody>
</table>

*Ploidy level was estimated by flow cytometry. **Means in the same column followed by the same lowercase letter are not different at the 0.05 probability level.

**Effect of colchicine concentration and treatment duration on survival and chromosome duplication of embryogenic calli**

In order to induce tetraploid plants from embryogenic calli, the embryogenic calli were cultured on MS liquid medium supplemented with 1 mg L⁻¹ kinetin and 0.1 mg L⁻¹ NAA containing 0.05, 0.10, 0.15 and 0.2% colchicine for 8, 14, 20 and 26 h. Only 11 individuals survived from all treatment. The ploidy level was estimated by flow cytometry. Two tetraploid plants were obtained from embryogenic calli treated with 0.10% colchicine for 14 h and 0.15% colchicine for 26 h (table 2).
Table 2: Effect of treatment duration and concentration of colchicine on survival and chromosome duplication of embryogenic calli of diploid ruzigrass

<table>
<thead>
<tr>
<th>Treatment duration (h)</th>
<th>Concentration (% w/v)</th>
<th>No. of explants treated</th>
<th>No. of explants survived (pieces/%)</th>
<th>Ploidy*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2X</td>
</tr>
<tr>
<td>8</td>
<td>0.05</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.10</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.15</td>
<td>30</td>
<td>1 (3.3)</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0.20</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>0.05</td>
<td>30</td>
<td>3 (10.0)</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>0.10</td>
<td>30</td>
<td>3 (10.0)</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>0.15</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>0.20</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
<td>30</td>
<td>1 (3.3)</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>0.10</td>
<td>30</td>
<td>1 (3.3)</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>0.15</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.20</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>0.05</td>
<td>30</td>
<td>1 (3.3)</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>0.10</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>0.15</td>
<td>30</td>
<td>1 (3.3)</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>0.20</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Ploidy level was estimated by flow cytometry. **There are no significant differences among different colchicine treatments (P>0.05)

**Thousand seed weight (TSW) of non-colchicine-treated ruzigrass (diploid) and tetraploid ruzigrass**

Follow thousand seed weight test, we were found that tetraploid ruzigrass no.14 had most average TSW 11.17 g. But tetraploid ruzigrass no.4, 13, 16 and diploid ruzigrass had lowest average TSW 6.276, 6.201, 6.268 and 6.209 g, respectively (table 3).

**Table 3: Thousand seed weight (TSW) of non-colchicine-treated ruzigrass (diploid) and various clones of tetraploid ruzigrass (Moisture content of seeds 10%)**

<table>
<thead>
<tr>
<th>Clones</th>
<th>Thousand seed weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diploid ruzigrass</td>
<td>6.209</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.1</td>
<td>8.161</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.2</td>
<td>8.655</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.3</td>
<td>8.278</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.4</td>
<td>6.276</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.5</td>
<td>9.345</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.6</td>
<td>9.232</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.7</td>
<td>9.293</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.8</td>
<td>8.119</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.9</td>
<td>8.303</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.10</td>
<td>8.522</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.11</td>
<td>8.547</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.12</td>
<td>8.366</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.13</td>
<td>6.201</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.14</td>
<td>11.17</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.15</td>
<td>7.080</td>
</tr>
<tr>
<td>Tetraploid ruzigrass No.16</td>
<td>6.268</td>
</tr>
</tbody>
</table>
Discussion [Conclusions/Implications]

This work presents the first success of tetraploid ruzigrass development in Thailand with various techniques. In previous studies, tetraploid ruzigrass have been induced from seeds germinated (Swenne et al., 1981; Ishigaki et al., 2009; Timbo’et al., 2014) and multiple-shoot clumps (Ishigaki et al., 2009). In this study, we tried to induce tetraploid ruzigrass from embryogenic calli because this technique was also used for polyploidization in some species successfully, such as the research of Chen and Goeden-Kallemeyn (1979). They induced tetraploid plants from colchicine-treated diploid daylily *Hemerocallis flava* L. callus. They found that over 50% of the plants initiated from the colchicine-treated calluses were completely tetraploid. Lan et al. (2010) induced polyploidy of Russian wild rye from colchicine-treated embryogenic calli, with a percentage of 53.58 tetraploid cells. However, we could develop only 3.3% of tetraploid for our study. This low rate of tetraploid may be due to some embryogenic calli were died after being treated by colchicine.

Moreover, some embryogenic calli were difficult to regenerate to plantlets. We also used apical meristems as the material, same as the work of Wu et al. (2013), which successfully induced tetraploid from apical meristems of *Clematis heracleifolia* the percentage of 80. Unfortunately, we could produce only 13.3 % of tetraploid.

Although inducing by seedling is the simplest method, it could not produce the unique genotypes due to the segregation of genes in crossing species. Ishigaki et al.(2009) mentioned that multiple-shoot clumps could be the appropriate technique to induce tetraploid as they can produce superior and unique tetraploid ruzigrass plants because multiple-shoots are used to produce superior and unique clumps can be clonally propagated through additional tissue culture application.

In this study, we also propose the simple screening of tetraploid genotypes using the weight of seeds. We can easily decrease clone numbers for the expensive flow cytometry ploidy identification method with this technique.

Acknowledgements

This research was financially supported by Bureau of Animal Nutrition Development, Department of Livestock Development.

References


Wu, Y.X., Li, W.Y., Dong, J., Yang, N., Zhao, X.M. and Yang, W. 2013. Tetraploid induction and
215-220.


melhoramento de *Brachiaria*. In: Clonagem de plantas por sementes: estratégias de estudo da
apomixia (Carneiro VTC and Dusi DMA, eds.). *Embrapa Recursos Genéticos e Biotecnologia, Brasília*, 47-65.
Differences in *Urochloa* hybrids and cultivars biomass production in several sites in western Kenya

Mwendia, S.W.; Notenbaert, A.O.; Mwangi, D.M.; Odhiambo, R.; Ogutu, I.; Juma, A.

1International center for tropical Agriculture (CIAT) P.O Box 823-00621, Nairobi
2Send a Cow- Kenya P.O. Box 1761-00500, Kakamega
3Kenya Agricultural and Livestock Research Organization (KALRO) P.O. Box 169-50100 Kakamega

Key words: dry matter; forage production; *Urochloa*

Abstract

Forage production is at the core of improved livestock productivity, especially in sub Saharan Africa. The genetic potential of existing animals remains underutilized due to limited forage quality and quantity. Albeit wide range of forage germplasm that exists, little data is available for identifying suitable genotypes, matched to specific environments and production systems. Due to the spatial and temporal diverse environments in which livestock production happens, multi-locational screening of forage production and characterizing genotype by environment interaction is key. We selected seven *Urochloa* (Syn. *Brachiaria*) genotypes comprising three hybrids and four cultivars and established them in on-farm trials in western Kenya for dry matter evaluation and nutritional quality. We selected eight sites covering four administrative counties (Siaya, Kakamega, Busia, Bungoma), and each county hosting two replicated trials, with each trial replicated 3 times. We observed dry matter yield differences across the counties in the order Bungoma > Busia > Kakamega > Siaya. Similarly, the genotypes returned varied performance across the sites. Hybrids did well in one of the county, a mix of hybrids and cultivars in two counties and cultivars in the last county. Amongst sites, variation was least in Busia, and more pronounced in Bungoma. Continued assessments in subsequent cuts are underway. These will feed into context-specific recommendations about suitable forages for sustainable intensification in the face of global warming.

Introduction

Feeds and forages account for 50–70% of costs in livestock production (Odero-Waitituh 2017). Persistent low livestock productivity in sub Saharan African (SSA) countries is largely attributable to insufficient feeds and forages. This goes against growing demand for animal source foods projected to double by 2030 (World Bank 2014), due to human population growth, urbanisation and changing diet patterns. Essentially, livestock production will have to grow to meet the projected demand. Meat and milk demand are growing at 2.8 and 2.2% respectively. The estimated consumers’ demand of 35 and 83 billion tons for meat and milk respectively by 2050 (World Bank 2014) will remain unmet if livestock feeding remain inadequately addressed. However, pressure on land is also increasing with smallholder systems no longer able to allocate land for grazing, necessitating and leading to intensified production, especially for dairy. Therefore, productive forage technologies suitable for intensification are desirable to address for livestock increased productivity. *Urochloa* forage species including its hybrids are successful in Latin America, supporting improved livestock productivity especially beef (Rivas and Holmann 2005). Similarly, this is possible in African tropics, especially in the humid and sub-humid environments, where dairy production dominates. While a wide range of livestock forages -including species, cultivars and hybrids- exist (http://www.tropicalforages.info/), matching genotypes to biophysical environment remains unsatisfactory in order to identify the most biophysical suitable lines that additionally match with the agricultural farming context.

We therefore, assessed under on-farm context, *Urochloa* hybrids and cultivars for their suitability in western Kenya, where despite dairy potential, a profound production gap prevails.
Materials and Methods

Site selection

We selected four counties in western Kenya based on dairy potential. The counties namely; Bungoma, Busia, Kakamega and Siaya. Despite the areas being mid altitude 900–1800m, they differ (Jaetzold and Schmidt 1983). Bungoma site is in low midland categorised as marginal sugar cane zone at an altitude ranging 1433-1829 m and receive 1536- 1681 mm of rainfall annually. Busia equally in low midland sugar zone at an altitude 1200-1440 m, receiving annual 1585 -1690 mm. Kakamega also in low midland sugarcane zone but at 1300-1550 meters altitude and annual precipitation of 1800mm, while Siaya’s is in lower midland zone ranging from LM1 to LM5. In LM4 where we had the trials have an annual average precipitation of 890-1020 mm and at altitude 1320 m. In conjunction with Send a Cow Kenya (SACK), a development partner with many years’ experience in the region, We linked to farmer groups that have been working with SACK on improving human nutrition and incomes. Livestock including dairy is one of the common agricultural activities, with milk contributing to household nutrition and incomes. We selected two farmer groups per county and sensitized them about dairy and the importance of animal feeding. We offered them to try out several forage options that could grow well in the region. In the end, the groups offered land where we established demonstration trials. While the project provided forage technologies and technical advice, farmers agreed to provide labour, for e.g. land preparation, planting, weeding and harvesting.

Forage technology design and management

We selected eight forage types comprising of three hybrids and four cultivars from genera \textit{Urochloa}. The hybrids included Cayman, Cobra, and Mulato II while the cultivars were Basilisk, Piata, Xaraes and MG4. As a check, Napier grass (\textit{Cenchrus purpureus} Syn. \textit{Pennisetum purpureum}) from the farmers’ farms was included among the treatments. In each site, we planted the forages in 15m² plots replicated 3 times, and across the 8 sites. For all forages, we followed the recommended seed-rates of 6 kg/ha for \textit{Urochloa} (Njarui et al., 2016) and for Napier grass we used splits placed at 1m x1 m grids (Mwenda et al., 2017). Because of acidic soils in western Kenya (Kanjanja et al., 2002), we applied lime at two t/ha. Farmers maintained plots weed-free as necessary.

Forage yield and quality

We harvested biomass every 8 weeks, thereby taking samples for dry matter analysis that we also processed for quality analysis. We implemented quality analysis with near infrared system (NIRs) on samples of one demonstration site/county and focused on metabolizable energy (ME), crude protein (CP), neutral detergent fiber (NDF) and in vitro organic matter digestibility (IVOMD). We derived yield metrics for metabolizable (ME MJ/ha) and crude protein (Kg CP/ha), by combining biomass yields and laboratory analysis results.

Data Analysis

We managed data in Microsoft excel and statistics in GenStat 18th edition

Results and discussion

Forage yields and quality

Forage dry matter yields across the counties were largely in the order Bungoma > Busia > Kakamega > Siaya (Figure 1). Cayman and Cobra hybrids produced similar biomass to cultivars in Bungoma and Busia but more than the cultivars in Kakamega and Siaya. Compared to Napier grass, all hybrids produced less especially in Kakamega and Busia.

![Figure 1](image_url)

**Figure 1**: Average biomass yield (four cuts) for Napier grass, \textit{Urochloa} cultivars and hybrids across Bungoma, Busia, Kakamega and Siaya counties in western Kenya, 2019
At forage type level, variability in *Urochloa*, was more pronounced in the hybrids than the cultivars and least in the Napier grass (Fig 1). County yield data revealed more variability in Bungoma County, followed by Kakamega, Siaya and least in Busia (Figure 2).

Crude protein yield (Kg CP/ha) and metabolizable energy yield (ME MJ/kg) had differences (P<0.05) at county level where Busia had most Kg CP/ha and ME MJ/kg than the other counties (Figure 3).

**Table 1**: Neutral detergent fiber and invitro organic matter digestibility of Napier grass, *Urochloa* hybrids and cultivars from Bungoma, Busia, Kakamega and Siaya counties based on second harvest in 2019 when the crops had undergone dry season.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>County</th>
<th>Napier</th>
<th>Cayman</th>
<th>Cobra</th>
<th>Mulato II</th>
<th>Basilisk</th>
<th>Piata</th>
<th>Xareas</th>
<th>MG4</th>
<th>P value</th>
<th>lsd</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF%</td>
<td>Bungoma</td>
<td>66.7</td>
<td>61.4</td>
<td>64.7</td>
<td>61.6</td>
<td>66.2</td>
<td>65.0</td>
<td>65.4</td>
<td></td>
<td>0.001</td>
<td>3.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(55.2)</td>
<td>(56.3)</td>
<td>(55.6)</td>
<td>(56.9)</td>
<td>(56.3)</td>
<td>(56.0)</td>
<td>(56.6)</td>
<td></td>
<td>(0.002)</td>
<td>(1.90)</td>
</tr>
<tr>
<td></td>
<td>Busia</td>
<td>63.1</td>
<td>61.7</td>
<td>63.1</td>
<td>62.0</td>
<td>65.8</td>
<td>69.8</td>
<td>64.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(56.9)</td>
<td>(60.1)</td>
<td>(60.7)</td>
<td>(61.9)</td>
<td>(59.7)</td>
<td>(60.8)</td>
<td>(56.7)</td>
<td></td>
<td>(62.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kakamega</td>
<td>67.6</td>
<td>59.5</td>
<td>59.7</td>
<td>62.4</td>
<td>64.7</td>
<td>64.7</td>
<td>65.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(54.6)</td>
<td>(60.4)</td>
<td>(60.7)</td>
<td>(60.9)</td>
<td>(59.3)</td>
<td>(57.7)</td>
<td>(58.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Siaya</td>
<td>64.9</td>
<td>60.6</td>
<td>65.8</td>
<td>60.9</td>
<td>66.5</td>
<td>65.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(53.9)</td>
<td>(57.0)</td>
<td>(55.6)</td>
<td>(56.8)</td>
<td>(58.5)</td>
<td>(56.1)</td>
<td>(55.4)</td>
<td></td>
<td>(55.7)</td>
<td></td>
</tr>
</tbody>
</table>

Attribute in brackets correspond to means in brackets along each row further relating to lsd and P values in brackets.

On the strength of dry matter yields and digestibility, Cayman, Xareas and Mutalo II would be more suitable in Bungoma and other similar environs, especially considering that Napier grass in the area...
is vulnerable to stunting disease (Kabirigi et al., 2015).

Basilisk, Piata and Cayman and in that order, had the most crude protein yield and the same order for metabolizable energy making them candidates of choice in Busia. However, accumulation of more NDF by Basilisk and Piata than Cayman (Table 1) despite the values being similar is undesirable. Only Napier grass and Xareas had significantly lower digestibility in the County making them least of choice in the area. In Kakamega County, Napier grass resulted in most crude protein yield due to the high dry matter yield (Figure 1) despite the values not being significantly different. Equally, Napier had most ME followed by Cobra > Basilisk. Albeit the competitive yields, Napier accumulating most NDF (Table 1) with subsequent lowest digestibility minimize choice on the Napier grass also exacerbated by stunting disease that is prevalent in the County leaving Cobra and Basilisk as best bet for Kakamega among the test forages.

In Siaya County, Napier grass least digestibility negated it relatively higher ME yield although the values were similar to those of other forages. As such, Piata > Xareas >MG4 crude protein yield, similar to ME yield except for interchange of Xareas and Piata, left the three preferable for Siaya. In general, Bungoma, Busia and Kakamega Counties, had a mix of Urochloa hybrids and cultivars doing well, while in Siaya only cultivars and therefore the best bets for forage production.

In conclusion, as we show here, performance of different forage types even within a species vary greatly under similar management at different locations. In the relatively drier site in Siaya than the other sites, Urochloa cultivars are preferable to either Napier grass or Urochloa hybrids. Therefore, recommendations based on field evaluations are more realistic where various environmental factors interplay and influence genotype performance.

Acknowledgements
We are grateful to the support by the smallholder farmers who undertook the forage demonstration trials and provided farms for the same. Financial support from GIZ to a project “Improved forage grasses: Making the case for their integration into humid- to sub-humid livestock production systems in Kenya and Ethiopia” is highly appreciated without which this work would not have been possible.

References


Formononetin of Red Clover (Trifolium pratense L.) as affected by water availability

Ortega-Klose, F. *; López-Olivari, R.1; Melo, M.1; Quiroz, A.2; Bardehle, L.3.

* Instituto de Investigaciones Agropecuarias, INIA Carillanca, km 10 camino Cajón-Vilcún s/n, Casilla 929, Temuco, Chile. www.inia.cl Email fortega@inia.cl; 1 Instituto de Investigaciones Agropecuarias, INIA Carillanca;
2 Universidad de La Frontera, Laboratorio de Ecología Química, Departamento de Ciencias Químicas 3 Recursos Naturales, www.ufro.cl Email andres.quiroz@ufro.cl; 3 Universidad de La Frontera, Departamento de Producción Agropecuaria.

Key Words: Formononetin, isoflavones, water availability, plant survival

Abstract
Red clover is a valuable legume in the world. Among the biotic factors limiting the persistence of the species in Chile is the root borer Hylastinus obscurus (Marsham). Our previous studies have shown a negative effect of formononetin content of the plant on the root borer fitness. This research aimed to assess the relationship between water availability and formononetin concentration. Two independent growth chamber experiments were established at Carillanca Research Center, INIA-Chile to study the effect of water availability on formononetin concentration in the aerial and root parts of the plants. In experiment I, three levels of water applied were studied: T1: non-stressed, maintained between 100 and 60% of the readily available soil water (RAW); T2: 60 and 30% of RAW; T3: <30% of RAW. Experiment II consisted of four water levels: T1: 100-80% RAW; T2: 80-60% RAW; T3: 60-40% RAW; T4: <40% RAW. In both experiments, a complete randomized design was used. For sampling, plants were dug up from the pots and cut at the crown to separate the aerial part from the crown and roots. Formononetin concentration was evaluated by extracting with a methanol solution and relative quantifications based on HPLC–MS. Different water available levels were studied. Formononetin was much higher in the aerial part compared to roots. However, there were no significant effects of readily available soil water (RAW) over formononetin concentration.

Introduction
Red clover (Trifolium pratense L.) is a valuable legume worldwide. The main limitation of the species is the lack of persistence related to the high mortality of plants due to a complex of biotic and abiotic factors (López-Olivari and Ortega-Klose 2020). Furthermore, there is a close relationship between plant population and forage yield potential (Ortega et al., 2014). Among the biotic factors associated with red clover mortality in Chile, the main one is the root borer Hylastinus obscurus (Marsham). Our previous studies of the relationship plant-borer mediated by semi-chemicals have shown that formononetin is the main isoflavone of red clover, eliciting an antifeedant response from H. obscurus (Quiroz et al., 2017; Quiroz et al., 2018). This research aimed to study the relationship between soil water availability and formononetin concentration.

Materials and Methods
Two independent experiments were established at Carillanca Research Center (38°41'SL and 72°25'WL), INIA-Chile, in a growth chamber maintained at 24/18°C day/night (14/10 hours) and 125 Photosynthetically Active Radiation (PAR) during the day. In both experiments, the diploid cultivar Superqueli INIA was sown in a greenhouse in seed trays and transplanted later to pots of 12.4 l each (22 cm deep; Andisol type soil with a loam texture). Fertilization was applied according to soil analysis, estimating the doses per pot to an equivalent of 40-113-329 kg/ha of N, K2O and P2O5, respectively. In experiment I, three levels of water applied were: T1: non-stressed, maintained between 100 and 60% of the readily available soil water (RAW); T2: 60 and 30% of RAW; T3: <30% of RAW. In this experiment, I, 5
plants per pot, were established with 36 pots in a complete randomized design with three levels of water applied, 2 evaluation dates and 6 pots per level and evaluation date. Experiment II consisted of four water levels: T1: 100-80% RAW; T2: 80-60% RAW; T3: 60-40% of RAW; T4: <40% of RAW. In this experiment II, 9 plants per pot were established with 32 pots in a complete randomized design with four irrigation levels, 2 evaluation dates and 4 pots per water level and evaluation date. Water was replenishing based on the weight of each pot. Experiment I was cut and evaluated the first time after 16 days of establishing the water treatments and then again assessed 33 days after the first cut. Experiment II was evaluated 36 days after establishing water treatments and 48 days later. For sampling, plants were dug up from the pots and cut at the crown to separate the aerial part from the crown and roots; crown and roots were carefully washed. After sampling, the aerial and root tissues were stabilized immediately by immersion in liquid N2 for later lyophilization. The yield of the aerial and root sections was evaluated (mg / g DM). Formononetin concentration was evaluated by extracting with a methanol solution and relative quantifications based on HPLC–MS. HPLC analysis was performed using a Diode Array Detector and a C18 reversed-phase column according to the methodology reported by Ramos et al. (2008). Moisture availability per pot (W/W) was evaluated weekly by the weight of each pot. In experiment II, the stomatal conductance using a steady-state porometer (SC-1 leaf porometer, METER Group, Inc. USA) was measured before each sampling date. Also, the chlorophyll concentration in the leaf was measured once in experiment II using a portable chlorophyll meter (SPAD-502, Minolta Camera Co. Ltd., Japan). Data were analyzed by ANOVA and means separated by Duncan (5%).

**Results**

Figure 1 shows the weight of pots during the second period of experiment II; the four water levels were maintained with three irrigations in this experimental period. There were clear responses in stomatal conductance and chlorophyll content. Stomatal conductance differences were significant and in accordance with water levels (Figure 2). Chlorophyll content was significantly higher with water deficit treatments (T1: 43.9 c; T2: 46.2 c; T3: 52.4 b; T4: 62.4 a). There was no significant response in the dry matter yield of both aerial and root sections.

The highest content of formononetin was found in leaves and stems compared to roots. In experiment I, there were non-significant tendencies to increase formononetin concentration in the aerial part with water stress; something similar occurred in experiment II (Figure 3).

![Figure 1](image-url): Average weight of pots under four levels of irrigation in the Experiment II. FC: Field capacity; WP: Wilting point. T1: 100-80% of the readily available soil water (RAW); T2: 80-60% RAW; T3: 60-40% RAW; T4: <40% RAW.
Figure 2: Stomatal conductance (mmol/m²/s') of each treatment before two sampling dates of Experiment II. Different letters within dates indicate significant differences (Duncan's test, p ≤ 0.05). T1: 100-80% of the readily available soil water (RAW); T2: 80-60% of RAW; T3: 60-40% of RAW; T4: <40% of RAW.

Experiment I. Sampling 1

Experiment I. Sampling 2

Experiment II. Sampling 1

Figure 3: Formononetin content (mg / g) of red clover aerial part (shoots and leaves) in two experiments and two sampling dates each. Experiment I: T1: non-stressed, maintained between 100 and 60% of the readily available soil water (RAW); T2: 60 and 30% of RAW; T3: <30% of RAW. Experiment II: T1: 100-80% of RAW; T2: 80-60% of RAW; T3: 60-40% of RAW; T4: <40% of RAW. Bars indicate the standard error of the means.

Discussion

Our results agree with previous reports regarding the higher content of formononetin in the aerial part compared to the roots (Ortega et al., 2015). There are few reports about the effect of abiotic factors such as water soil level on the isoflavones concentration. The isoflavone content in soybean seeds has a high level of genetic control by numerous small-effect QTL (G), the environment (E) and the interaction of G x E (Gutierrez-Gonzalez et al., 2010). Agronomic studies showed that depending on the level of stress, in non-irrigated soybean compared with irrigated fields, a decrease of 2.5-fold in isoflavonoids occurred (Bennett et al., 2004). High levels of water deficit decreased isoflavone content in soybean seeds in field studies (Al-Tawaha et al., 2007).

On the other hand, in red clover under waterlogging conditions, the concentration of the isoflavonoid biochanin A in leaves increased two to three times after 3 weeks of treatment (De Rijke et al., 2005). On the contrary, our results did not show an increase of formononetin content in treatments with water stress; moreover, there was no significant effect of available soil water on formononetin concentration in the aerial part and roots of red clover. Considering the repellent effect elicited by formononetin on H. obscurus, the non-effect shown by water availability can be considered a good result since the genetic expression of formononetin content in selected red clover genotypes will be independent of the soil available water level.
Conclusions

There was a higher concentration of formononetin in the aerial parts of red clover compared to roots. There was no significant effect of soil water availability on formononetin content; this is a positive finding if a red clover genetic line with a higher formononetin content is selected since the expression of the trait will be independent of the water soil available level. It is necessary to study other abiotic soil factors (phosphorus level as an example) and confirm these findings in field conditions.

Acknowledgments

This work was supported by INIA grant 500302-70, FONDECYT grants 1070270, 1100812, 1141245 and 1181697.

References


Evaluation of yields and nutritive composition of dual purpose sweet potato vine cultivars for forage use

Kenana, R.S.; Hoka, A.I.; Ondabu, N.; Ondabu, F.; Mercy, J.
Kenya Agricultural and Livestock Research Organization, Beef Research Institute - Lanet
P.O. Box 3840, Nakuru, Kenya.

Key words: cultivar; digestible energy; feed; fodder; protein

Abstract
The sweet potato vine (SPV) is a widely grown but underutilized feed resource for livestock. The vines have desirable characteristics suitable for fodder production due to high contents of protein and digestible energy. The objective of this study was to evaluate the yield and nutritive composition of five dual purpose cultivars based on vine production for forage use. The experimental design was arranged in randomized complete block design where six cultivars of sweet potato were established in plots of 2.5m x 2.5m in three replicates. The cultivars used were; Kenspot 1, 2, 3, 4, and 5. An improved forage type cultivar (Wagbolige) served as a control. Data was subjected to analysis of variance (ANOVA) using a general linear model (SAS, 2002). Results showed that there was no significant difference \((p<0.05)\) in dry matter (DM) among the cultivars. Wagabolige (control) was much superior in yield \((p<0.05)\) compared to the others cultivars. There was no significant difference \((p<0.05)\) in yield between Kenspot 1, 3, 4 and 5. Kenspot 2 had the lowest yields. Kenspot 1 had the highest CP \((p<0.05)\) compared with the other 5 cultivars. However, there was no significant difference \((p<0.05)\) in CP between Kenspot 5, Kenspot 2 and Wagabolige. Kenspot 3 had the lowest CP content among the cultivars. Energy was highest in Kenspot 1 and lowest in Kenspot 2. NDF and ADF were highest in Kenspot 2 and lowest in Kenspot 4. There was no significant difference \((p<0.05)\) in Ca, P, K and Mg. This study concluded that the five dual purpose cultivars demonstrated excellent potential in terms of quality for forage use. Biomass production however, was the main limitation.

Introduction
The increasing population and diminishing land sizes, has reduced the land available for forage production, as the little land available is used for growing food crops (FAO 2006). This has necessitated the need to identify multipurpose crops which can be used both as human food and livestock feeds. In recent years, sweet potato \((Ipomoea batatas)\) has elicited a lot of interest from various research organizations and governments due to its adaptability to semi-arid areas and the possibility of being used both as human food and livestock feed. However, there is limited information on its contribution to livestock production in sub-Saharan Africa and as a result its potential as livestock feed has not been fully exploited (Peter 2008).

Studies conducted at the International Potato Centre (CIP) in 2008 revealed that farmers preferred the dual purpose varieties because they have enough tubers for human consumption as well as fodder for livestock. The dual purpose cultivars are particularly preferred because harvesting can be done throughout the growing season. In Kenya about 59.2 thousand ha of land is grown with sweet potato annually with a production of 12.8t/ha (FAO 2012). However, the amount of vines produced alongside has not been documented. Sweet potato vines (SPVs) can play a significant role as a partial replacement for other forages and pastures in the nutrition of dairy cows, goats and pigs in East Africa (Peters 2008). A study conducted in Uganda to determine the potential of sweet potato vine-based diets as partial milk substitute (PMS) for dairy calves reduced the amount of milk consumed per calf by 120 litres over the 70-day period (Taabu et al., 2016).

In recent years several sweet potato varieties were released for various agro-ecological zones at the Kenya Agricultural and Livestock Research Organization (KALRO), Foods Crops Research...
Institute in Njoro. These included cultivars; Kenspot 1, Kenspot 2, Kenspot 3, Kenspot 4, Kenspot 5 among others. However, studies on biomass and nutritional value for livestock are missing and this study is a step towards filling this knowledge gap.

**Materials and Methods**

This study was carried out at KALRO-Lanet situated in Nakuru County. The center lies between longitude 36° 09’ E and latitude 0° 18’ S at an altitude of 1920 m above sea level. The center occupies 1418 hectares of land within two Agro ecological zones (AEZs), where 20% of the land lies within AEZ III and 80% in AEZ IV (Jaetzol et al., 2006). The region has a bimodal rainfall season with the (long rains) starting from March to June and the (short rains) falling from November to December. The annual rainfall ranges between 600-1000 mm and temperatures between 10°C and 30°C (Jaetzol et al., 2006). Soil pH ranges between 5.5- 6.5. Soils are deep sandy loam with good water holding classified as humic nitosols under Food and Agricultural Organization of the United Nations (FAO) classification.

**Cultivation of Forage Sweet Potato**

The land was prepared into a fine seed bed. The land was divided into 18 plots of 2.5m x 2.5m with a 1-meter-wide path way between the plots. A randomized complete block design (RCBD) was use to layout the experiment. Six cultivars of SPV namely Kenspot 1, Kenspot 2, Kenspot 3, Kenspot 4, Kenspot 5 and Wagabolige were planted randomly in three replicates. Wagabolige which is an improved forage type sweet potato cultivar (Ondabu et al., 2007) was chosen as the control cultivar. The cultivars were planted on their respective plots using 50 cm long cuttings, in holes dug on the flat ground in rows 60 cm apart and the plants were spaced 30 cm apart within rows. A base fertilizer dressing with Di-ammonium phosphate was done at planting and top dressing at 45 days after planting. The fertilizer was applied according to Wielemaker and Boxem (1982) during planting at the rate of 54 and 20 kg ha–1of nitrogen (N) and phosphorus (P), respectively; and after establishment (45 days after planting), the blocks were cut back and top dressed with 52 kg ha–1N. Potassium was not applied as soils in Lanet area were known to contain adequate potash to meet the requirements for normal growth of forage sweet potato cultivars (Wielemaker and Boxem 1982). These blocks were kept clean by regular hand weeding and the subsequent re-growth was harvested at 120 days

**Results**

**Yield and Nutrient Composition**

The yield and composition of the cultivars are shown in Table 1. Wagabolige, the control cultivar, apparently produced the highest biomass quantity (p<0.05) followed by Kenspot 3, Kenspot 4, Kenspot 1, Kenspot 5 and Kenspot 2 respectively. Kenspot 4 had the highest dry matter (DM) though not significant (p<0.05) from the other cultivars, while Kenspot 3 had the lowest. There was no major significant difference in energy among the cultivar though Kenspot 1 had the highest while Kenspot 2 had the lowest. Crude fibre (NDF and ADF) was highest (p<0.05) in Kenspot 2 and lowest in Kenspot 1. Crude protein (CP) was highest (p<0.05) in Kenspot 1 and lowest in Kenspot 3. There was no significant difference (p<0.05) in Ca, P, K and Mg among the cultivars.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Yield t/ha</th>
<th>DM%</th>
<th>Crude Protein (%)</th>
<th>Energy (Kcal)</th>
<th>NDF %</th>
<th>ADF %</th>
<th>Ca %</th>
<th>P %</th>
<th>K %</th>
<th>Mg %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenspot 1</td>
<td>29.4b</td>
<td>13.02</td>
<td>23.70</td>
<td>2084.05</td>
<td>40.15</td>
<td>21.50</td>
<td>1.29</td>
<td>0.36</td>
<td>4.60</td>
<td>0.39</td>
</tr>
<tr>
<td>Kenspot 2</td>
<td>16.4c</td>
<td>12.93</td>
<td>19.23</td>
<td>1757.09</td>
<td>46.11</td>
<td>28.78</td>
<td>1.26</td>
<td>0.34</td>
<td>4.79</td>
<td>0.39</td>
</tr>
<tr>
<td>Kenspot 3</td>
<td>31.7b</td>
<td>12.92</td>
<td>16.84</td>
<td>1793.62</td>
<td>42.28</td>
<td>24.96</td>
<td>1.23</td>
<td>0.31</td>
<td>4.73</td>
<td>0.39</td>
</tr>
<tr>
<td>Kenspot 4</td>
<td>29.2b</td>
<td>13.73</td>
<td>21.82</td>
<td>1911.84</td>
<td>42.85</td>
<td>23.29</td>
<td>1.19</td>
<td>0.37</td>
<td>5.33</td>
<td>0.31</td>
</tr>
<tr>
<td>Kenspot 5</td>
<td>19.5d</td>
<td>13.50</td>
<td>19.78</td>
<td>1785.06</td>
<td>43.02</td>
<td>25.46</td>
<td>1.38</td>
<td>0.38</td>
<td>5.61</td>
<td>0.36</td>
</tr>
<tr>
<td>Wagabolige</td>
<td>64.5d</td>
<td>13.12</td>
<td>19.60</td>
<td>1846.22</td>
<td>42.94</td>
<td>24.40</td>
<td>1.29</td>
<td>0.33</td>
<td>4.95</td>
<td>0.36</td>
</tr>
<tr>
<td>Average</td>
<td>32.1</td>
<td>13.2</td>
<td>20.2</td>
<td>1863.1</td>
<td>42.9</td>
<td>24.7</td>
<td>1.27</td>
<td>0.35</td>
<td>4.97</td>
<td>0.37</td>
</tr>
<tr>
<td>CV%</td>
<td>13.3</td>
<td>3.6</td>
<td>2.5</td>
<td>0.1</td>
<td>0.68</td>
<td>1.1</td>
<td>11.1</td>
<td>13.7</td>
<td>9.9</td>
<td>12.5</td>
</tr>
</tbody>
</table>

a, b, c, d: means with same superscripts in the column are not significantly different (P>0.05). DM: dry matter, CP: crude protein, NDF: neutral detergent fibre, ADF: acid detergent fibre, Ca: calcium, P: phosphorous, K: Potassium and Mg: Magnesium

---

**Table 1: Yield and chemical composition of six cultivars of sweet potato vines**
Discussion

Yield and Nutrient Composition

The forage type sweet potatoes (SPV) are generally high in biomass production. This presented itself very well in this study. Cultivar (Wagabolige) an improved forage type (Ondabu et al., 2007) produced the highest yields (8.5ton/ha). This is more than double the highest among the dual purpose cultivars (4.1ton/ha). The six cultivars had a CP range of 16% to 23%. This agrees with the range given by Dung (2001). All the cultivars were generally of high nutritional quality. They had much higher CP more than the 80 g CP/kg DM, below which forages are considered low in quality (Irungu et al., 2016; Dung, 2001). The NDF was also below the 600 g/kg DM usually considered as the threshold for ruminants (Irungu et al., 2016; Meissner et al., 1991). The low NDF was consistent with the general observation of lower NDF in non-grass fodders (Minson 1990). Nonetheless, all forage sweet potato cultivars in the current study had higher NDF than 150 g/kg DM recommended by Strasia and Gill (1990) as being suitable for growing ruminants. Furthermore, these cultivars contained lower than 600 g NDF/kg DM, beyond which a feed is classified as poor quality (Meissner et al., 1991). Acid detergent fiber is associated with the digestibility of a feed, thus a feed with high ADF is less digestible than that of low ADF and a less digestible feed reduces the intake by animals.

Conclusions

All cultivars were similar in terms of DM, energy and minerals (Ca, P, K and Mg). These cultivars however, differed in yields, CP, NDF, and ADF. The six cultivars had superior feed qualities for livestock as they contained high CP and less fibre compared to common Kenyan forages. They were also high in energy, which classified them as high quality forages. However, the dry matter was low and might not be sufficient to meet the dry matter requirement of the animals if fed solely. They are, therefore, recommended to livestock farmers as high quality forage supplements. Additional trials are needed to determine their performance on livestock.

Acknowledgements

I wish to acknowledge my employer Kenya Agricultural and Livestock Research Organization (KALRO) and the Institute Director, KALRO-BRI-Lanet for logistical and financial support.

References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forage legume ecosystem services in sustainable livestock systems
Forage legumes in tropical regions: recent advances and future challenges

Casagrande, D.R.¹; Homem, B.G.C.²; Boddey, R.M.²

¹Federal University of Lavras, Lavras, Brazil; ²Embrapa Agrobiologia, Seropedica, Brazil.

Key words: Arachis pintoi; beef cattle; Brachiaria spp.; management targets; warm-season legume

Abstract

Nitrogen input in tropical pastures increases forage and animal productivity. Forage legumes can fix atmospheric nitrogen and are the most economical way to add this nutrient to the soil. Our objective was to report the benefits of forage legumes in tropical pastures and possible strategies to implement different forage legumes. In tropical conditions, such as in Brazil, the use of forage legumes is still scarce. Even with low legume adoption on tropical pastures, forage legumes can provide ecosystem services. Increased animal productivity is the first ecosystem service provided by these legumes, mainly due to the addition of nitrogen that, is typically the most limiting nutrient on tropical soils and yet the most important driver of plant growth and development. Legumes also provide an opportunity to increase nitrogen cycling in grassland, reducing grassland degradation. Pastures that include legumes have greater litter quality than grass monocultures, increasing soil organic matter faster. Legumes improve diet nutritive value and animal performance, resulting in reduced enteric methane emissions per unit of animal product.

Additionally, legumes are generally associated with lower nitrous oxide emissions than N-fertilized grass swards and reduce the carbon footprint from the system due to nitrogen manufacture, transport, storage, and application. However, the greatest challenge in tropical pastures is to increase the adoption of forage legumes. Therefore, it is necessary to understand the role of different legumes in the pasture environment. Some legumes have high herbage accumulation and biological nitrogen fixation potential, but they have low canopy stability; nonetheless, they could be used on short-lived pastures as well as integrated crop-livestock systems. When the objective is to achieve grass-legume stability in mixed pastures, it is necessary to use clonal propagation legumes and provide appropriate defoliation management to minimise light competition among plant communities.

Introduction

For a long time in Brazil, erroneously, it was believed that tropical legumes did not have persistence. The belief in lack of persistence spread among Brazilian researchers, technicians, and farmers such that the use of mixed pastures was thought to be unfeasible. However, recent studies demonstrate the mechanisms that determine if a legume will persist or not, and the success of a persistent mixed pasture will depend on light management. Furthermore, studies showed the potential benefits of the tropical legume introduction in grass pastures on nitrogen cycling, animal production, and greenhouse gas emissions. Thus, this full paper aims to describe some research results with forage legumes in tropical regions, especially in Brazil, and the future challenges of using mixed pastures.

Grazing management of herbaceous legumes

Propagation mechanisms of legumes

It is believed that the lack of persistence of legumes in mixed pastures in tropical regions was due to physiological incompatibility between tropical grass (C4) and legume (C3). However, recent studies have shown physiological differences between grass and legume (Boddey et al., 2020). Therefore, compatibility between the species can be defined as the ability of species to form a stable mixed sward. The stability of a canopy with biological diversity is defined by two aspects: resilience and resistance (Lake 2013). The resilience of mixed pastures is their ability to return to their original state after a disturbance, and resistance is their ability to remain in balance. Several factors are determinants of grass and legume compatibility, such as propagation
mechanisms and grazing management (Black et al., 2009). The propagation mechanisms of legumes have several important differences that will determine the position of shoot meristems and contribute to how different species tolerate grazing and mowing. In Brazil, Herbaceous legumes with potential for use in the mixed pasture have two forms of propagation: reproductive (crown formers) or clonal (stolon formers).

Crown-forming legumes
Crown-forming legumes in the tropics are the most abundant species, such as *Stylosanthes*, *Calopogonium*, *Centrosema*, *Pueraria*, and *Neonotonia*. Often in mixed pastures, including these legumes, low persistence has been reported. The stability of the crown-forming legumes in mixed pasture depends on the plant’s lifetime (main axis). In these cases, the average time the legume remains above 20% of the forage mass varies from 2 to 4 years (Alves et al., 2016; Depablos et al., 2020). Over time, these plants suffer from defoliation stress (selective grazing) because their growth points are exposed in the upper canopy layers (Faverjon et al., 2017). Another factor is the damage to the crown by treading. However, using these legumes in mixed pastures may bring positive short-term results, but it should be kept in mind that their persistence will be limited. Nevertheless, these legumes can have a residual effect of increasing N in the soil due to the large litter biomass deposited (Cadisch et al., 1994).

Clonal legumes
Legumes that develop stolons or rhizomes can increase through vegetative propagation producing clonal growth and having greater potential compatibility in a mixed canopy. This is the case of *Arachis pintoi* (forage peanut) and *Desmodium heterocarpon* subsp. *Ovalifoium* (Boddey et al., 2020). Clonal propagation allows even decapitation or death of the main axis of the plant as young stolons can survive (Faverjon et al., 2017). In stoloniferous legumes, the success of greater compatibility with grasses and resilience will depend on light management. Studies in tropical regions have shown that grazing management targets used in grass pastures (Figure 1; Gomes et al., 2020) optimise the N cycling in mixed pastures. In rotational stocking, less frequent defoliations, such as those obtained in 100% of light interception, should be avoided because they reduce the proportion of legume in the litter, negatively affecting the N cycling in Marandu palisadegrass and forage mixed peanut pastures (Figure 1; Gomes et al., 2020).

On animal production
In tropical regions, the productivity of livestock production on pasture in a sustainable manner becomes necessary. For example, in Brazil, the long-term experiment (9 years) showed that Marandu palisadegrass and forage mixed peanut pasture sustained significantly greater beef cattle production (789 kg/ha/yr.) compared to N-fertilized (120 kg of N/ha) grass monoculture (655 kg/ha/yr.; Pereira et al., 2020). In another study with Marandu palisadegrass and forage mixed peanut pasture, there was an increase of 34.5% in the live weight gain per area compared to grass monoculture without N application (Homem et al., 2021). Therefore, live weight gain per area in the mixed pasture in this study was 429 kg/ha/yr., four-time that of the Brazilian average. Furthermore, livestock grazing on grass-legume pasture may improve the balance between crude

and forage peanut (Tamele et al., 2018). Under rotational stocking, similar to recommendations for the management of grasses, interruption of the rest period is currently recommended when the mixed canopy of Marandu palisadegrass and forage peanut attains 95% of light interception (Gomes et al., 2018).

Positive impacts of the introduction of forage legumes in pastures
Legumes can contribute significantly to nitrogen (N) input in grazing systems. In mixed pastures, biological N2 fixation from the legume-rhizobia symbiosis is the primary N source to the soil-plant-animal systems in the absence of N fertilisation (Herridge et al., 2008). Thus, the most important transference pathways of the N fixed by legume to the companion grass are via litter or livestock excretion (Dubeux Jr. et al., 2007). Legumes have a greater nutritional value than grass, which positively affects the deposited litter quality, increasing the litter decomposition rate and N cycling to the system (Gomes et al., 2020). Furthermore, the proportion of legumes in the litter is the key to N cycling success in mixed pastures. The proportion of legumes in the litter is directly correlated with the legume in the pasture (Gomes et al., 2020). Therefore, grazing management targets that allow a desirable botanical composition (from 20% to 45% of legume in forage mass) optimise the N cycling in mixed pastures. In rotational stocking, less frequent defoliations, such as those obtained in 100% of light interception, should be avoided because they reduce the proportion of legume in the litter, negatively affecting the N cycling in Marandu palisadegrass and forage mixed peanut pastures (Figure 1; Gomes et al., 2020).

**Crown-forming legumes**

Crown-forming legumes in the tropics are the most abundant species, such as *Stylosanthes*, *Calopogonium*, *Centrosema*, *Pueraria*, and *Neonotonia*. Often in mixed pastures, including these legumes, low persistence has been reported. The stability of the crown-forming legumes in mixed pasture depends on the plant’s lifetime (main axis). In these cases, the average time the legume remains above 20% of the forage mass varies from 2 to 4 years (Alves et al., 2016; Depablos et al., 2020). Over time, these plants suffer from defoliation stress (selective grazing) because their growth points are exposed in the upper canopy layers (Faverjon et al., 2017). Another factor is the damage to the crown by treading. However, using these legumes in mixed pastures may bring positive short-term results, but it should be kept in mind that their persistence will be limited. Nevertheless, these legumes can have a residual effect of increasing N in the soil due to the large litter biomass deposited (Cadisch et al., 1994).

**Clonal legumes**

Legumes that develop stolons or rhizomes can increase through vegetative propagation producing clonal growth and having greater potential compatibility in a mixed canopy. This is the case of *Arachis pintoi* (forage peanut) and *Desmodium heterocarpon* subsp. *Ovalifoium* (Boddey et al., 2020). Clonal propagation allows even decapitation or death of the main axis of the plant as young stolons can survive (Faverjon et al., 2017). In stoloniferous legumes, the success of greater compatibility with grasses and resilience will depend on light management. Studies in tropical regions have shown that grazing management targets used in grass pastures (Figure 1; Gomes et al., 2020) optimise the N cycling in mixed pastures. In rotational stocking, less frequent defoliations, such as those obtained in 100% of light interception, should be avoided because they reduce the proportion of legume in the litter, negatively affecting the N cycling in Marandu palisadegrass and forage mixed peanut pastures (Figure 1; Gomes et al., 2020).

**On animal production**

In tropical regions, the productivity of livestock production on pasture in a sustainable manner becomes necessary. For example, in Brazil, the long-term experiment (9 years) showed that Marandu palisadegrass and forage mixed peanut pasture sustained significantly greater beef cattle production (789 kg/ha/yr.) compared to N-fertilized (120 kg of N/ha) grass monoculture (655 kg/ha/yr.; Pereira et al., 2020). In another study with Marandu palisadegrass and forage mixed peanut pasture, there was an increase of 34.5% in the live weight gain per area compared to grass monoculture without N application (Homem et al., 2021). Therefore, live weight gain per area in the mixed pasture in this study was 429 kg/ha/yr., four-time that of the Brazilian average. Furthermore, livestock grazing on grass-legume pasture may improve the balance between crude

and forage peanut (Tamele et al., 2018). Under rotational stocking, similar to recommendations for the management of grasses, interruption of the rest period is currently recommended when the mixed canopy of Marandu palisadegrass and forage peanut attains 95% of light interception (Gomes et al., 2018).

**Positive impacts of the introduction of forage legumes in pastures**

Legumes can contribute significantly to nitrogen (N) input in grazing systems. In mixed pastures, biological N2 fixation from the legume-rhizobia symbiosis is the primary N source to the soil-plant-animal systems in the absence of N fertilisation (Herridge et al., 2008). Thus, the most important transference pathways of the N fixed by legume to the companion grass are via litter or livestock excretion (Dubeux Jr. et al., 2007). Legumes have a greater nutritional value than grass, which positively affects the deposited litter quality, increasing the litter decomposition rate and N cycling to the system (Gomes et al., 2020). Furthermore, the proportion of legumes in the litter is the key to N cycling success in mixed pastures. The proportion of legumes in the litter is directly correlated with the legume in the pasture (Gomes et al., 2020). Therefore, grazing management targets that allow a desirable botanical composition (from 20% to 45% of legume in forage mass) optimise the N cycling in mixed pastures. In rotational stocking, less frequent defoliations, such as those obtained in 100% of light interception, should be avoided because they reduce the proportion of legume in the litter, negatively affecting the N cycling in Marandu palisadegrass and forage mixed peanut pastures (Figure 1; Gomes et al., 2020).
protein and digestible organic matter intakes, increasing the apparent efficiency of N utilisation and, consequently, decreasing N excretion to the environment (Homem et al., 2021). Therefore, this system had significant environmental benefits since the need for fossil fuel N fertiliser synthesis was eliminated. In addition, there are direct benefits for the farmers, with a reduction in the cost of maintenance and an increase in the gross income.

**On greenhouse gas emissions**

In Brazil, the increased proportional contribution of the Agricultural sector on the greenhouse gas has focused attention on the methane and nitrous oxide emissions from beef and dairy cattle, which are estimated to contribute approximately 80% of the emissions in this sector (Boddey et al., 2020). The introduction of legumes into the diet may reduce this emission is a powerful motivation to introduce incentives for the adoption of mixed pasture for beef or dairy production. In a recent study in Brazil, a mixed pasture of Marandu palisadegrass and forage peanut reduced the enteric methane emission in Nellore heifers by approximately 12% compared to grass monoculture with or without nitrogen fertiliser (Boddey et al., 2020). Thus, secondary metabolites such as tannins and saponins make the legume a potential mitigator of enteric methane. Furthermore, tannins in the legumes may help reduce urinary N excretion with consequent mitigation of nitrous oxide emission. Without any doubt, N fertiliser substitution for forage legumes without loss of animal production immediately leads to a mitigation of approximately 4.5 kg CO2 per kg N fertiliser applies related to the fossil energy employed (Roberson and Grace 2004).

![Figure 1: Nitrogen cycling via litter and excreta in Marandu palisadegrass-forage peanut pastures affected by defoliation frequencies. Bars with different lowercase letters compare defoliation frequency (P < 0.10). Errors bars represent ± standard errors of the means; 90LI, 90% light interception; 95LI, 95% light interception; 100LI, 100% light interception. Data from Gomes et al., (2020).](image)

**Final remarks and future challenges**

The use of legumes in mixed pastures for tropical regions has emerged as a feasible strategy to keep meat and milk production at levels acceptable to farmers with reduced greenhouse gas emission rates. Additional benefits are increased ecosystem biodiversity, improved soil fertility, and increased soil organic matter, contributing to further gas mitigation by CO2 sequestration for perhaps as long as two decades.

As future challenges, the adoption strategy of crown-formers legumes will need to be studied. As in integrated crop-livestock systems, Crown-formers legume species have shown some potential in pastures that need a legume for just a year or two. In the future, farmers that adopt integrated crop-livestock systems with mixed pasture will have benefits from these legumes in the pasture phase. Another future challenge is decreasing the establishment time of the forage peanut. Forage peanut has been reported to be slower to establish than grasses. Thus, the association of forage peanut with other legumes with the faster establishment in multiple species pasture may enhance the benefits of the legume in lesser time.

**Acknowledgments**

The authors gratefully acknowledge the FAPEMIG, CNPq, CAPES, and INCT-CÁ.
References


Sustainable Intensification of Livestock Systems Using Forage Legumes

Dubeux, J.C.B., Jr.¹; Sollenberger, L.E.²

¹Associate Professor, University of Florida – North Florida Research and Education Center, 3925 Highway 71, Marianna, FL, 32446.
²Distinguished Professor, University of Florida, Agronomy Department, Gainesville, FL, USA, 32611.

Key words: biological N₂ fixation; ecosystem services; sustainability

Abstract

Global human population is increasing and expected to reach 9.7 billion people by 2050. Sustainable intensification (SI) of agricultural systems is key to increase food production while minimizing impact on global natural resources. Forage legumes provide a myriad of ecosystem services (ES) and represent an important tool for promoting SI in livestock systems. Forage legumes associate with soil microorganisms to reduce atmospheric N₂. This N input represents a valuable contribution to increase net primary productivity with reduced C footprint. In addition, forage nutritive value generally increases, resulting in greater animal performance. When forage legumes are integrated into livestock systems, they complement the essential role of grasses by adding N to the system, improving forage quality, sharing resources with the companion grass, and enhancing soil organic matter. Soil C:N ratio is typically in a narrow range; therefore, input of N is essential to increase C sequestration and maintain the soil C:N ratio. Additional ES provided by forage legumes include enhanced efficiency of nutrient cycling, improved pollinator habitat, medicine/food for humans, timber, wildlife habitat, and shade for livestock (tree legumes). There are options of herbaceous and arboreal legumes, as well as annuals and perennials. In temperate regions, herbaceous legumes are used widely (e.g., Medicago sp, Trifolium sp.) while arboreal legumes are often found in tropical regions. There are a few options of herbaceous perennial warm-climate legumes, and some of them are still underexploited (e.g. Arachis pintoi, Arachis glabrata). Documented examples of forage legumes increasing livestock productivity are available in different regions of the world, and recent progress has been made in developing and managing forage legume germplasm adapted to biotic and abiotic stresses in tropical America, Africa, Southeast Asia, and Australia. Learning past lessons and applying the knowledge to shape the future is essential to achieve SI of livestock systems.

Introduction

Global human population is rapidly increasing, and the projection is to reach 9.5 billion people by 2050 (United Nations 2013). Therefore, it is essential to increase food production to supply the increasing food demand. In addition to the challenge to increase food production, there is evidence that recent economic advances have been made at the cost of global natural resources, with increasing threat to biodiversity and quality of life (Whitmee et al., 2015). Agricultural land is a limited resource, and the challenge is to produce more food per unit of land and resource input, while diminishing the threat for global natural ecosystems. Animal-food sources play a key role in the nutrition of future generations. Meat and milk from livestock are important food sources during early-stage development of humans, having a crucial role in the cognitive skills of children (Hulett et al., 2014). Developing sustainable livestock systems to supply nutrient-dense foods to sustain human development over the next decades is a critical step.

Sustainable intensification (SI) of livestock systems requires greater output of animal products per unit of resource input while reducing negative environmental impacts (Tedeschi et al., 2015; Dubeux et al., 2017a). Forage legumes are key to achieve SI in livestock systems because they can reduce N inputs from industrial fertilizer, increase animal performance, and enhance delivery of other ecosystem services (Sollenberger et al., 2019). There are numerous ways to integrate forage legumes into livestock systems in both space and time. Forage legume options include annual or perennial, herbaceous or arboreal, and adaptation to either cool or warm seasons. Climate
and soil attributes at a regional scale and at the planting site will dictate the optimal choices. Other factors affecting choice of forage legume include seed availability, management expertise, and socioeconomic aspects of local production systems.

In subtropical areas with defined warm and cool seasons, it is possible to overseed perennial warm-season pastures with cool-season forages, including forage legumes (e.g., *Trifolium* sp.). If a perennial warm-season legume is present (e.g., *Arachis glabrata* Benth.), the system would have N inputs both in the warm and cool seasons (Garcia-Jimenez 2019). In many tropical regions, there is one defined forage growing season and the major limitation in the reminder of the year is reduced rainfall. In this case, herbaceous annual legumes would contribute mostly during the rainfall season, although some potential benefits might carry over to the dry season (Boddey et al., 2020). In the tropics, there are multiple options of arboreal legumes with potential for use in silvopasture systems (Apolinário et al., 2016; Costa et al., 2016; Santos et al., 2020). Because of the perennial nature of these arboreal legumes, they might contribute both in the rainy and dry seasons.

This review paper will address how forage legumes are key components for SI of livestock systems. We will explore how forage legumes can assist by producing more output per unit of resource input (provisional ecosystem services) while maintaining the delivery of other ecosystem services (ES) that are beneficial to the environment.

**Provisional ecosystem services**

Livestock performance is one of the major reasons producers around the world integrate forage legumes into grazing systems. There are numerous reports indicating greater livestock performance when forage legumes are present in the cattle diet, especially during the warm season in tropical regions (Garay et al., 2004; Gomes da Silva et al., 2020 in press). Greater livestock performance occurs because often forage legumes have greater digestibility and crude protein concentration than C4 grasses (Garcia-Jimenez, 2019), resulting in greater intake of digestible organic matter. Besides livestock performance, forage legumes might provide other marketable products, such as firewood, timber, fruits, and pods (Apolinário et al., 2016; Dubeux et al., 2017b). These products are obtained with lesser off-farm inputs and, in most of the cases, are economically viable, which are two important premises of SI.

**Supporting ecosystem services**

Forage legumes are also intertwined in multiple aspects of supporting ES. Nutrient cycling and biological N fixation (BNF) are perhaps two of the most important supporting ES delivered by forage legumes. Grassland systems are typically N-depleted environments, and this depletion tends to increase with grazing livestock. Piñeiro et al., (2010) observed greater soil organic matter C:N ratio at grazed sites compared with ungrazed sites for 67 paired comparisons. They concluded that C sequestration and grassland productivity can be simultaneously increased by increasing N retention at the landscape level. This highlights the fact that integrating forage legumes might enhance soil organic matter (SOM) formation and C sequestration. In fact, there are numerous examples of enhanced soil C sequestration and SOM formation when integrating forage legumes (Fisher et al., 1994; Tarré et al., 2001; Liu et al., 2017). Another aspect that might contribute to greater SOM formation when integrating forage legumes is the increase in net primary productivity. Greater plant species richness often is linked to greater primary productivity, especially when it comes along with diversification of functional groups (Tilman et al., 2006). This is precisely the case when integrating legumes into grass monocultures. Enhancing SOM formation and C sequestration, BNF, and net primary productivity are key ingredients for the SI of livestock systems and forage legumes are an important component of these processes.

**Regulating ecosystem services**

Regulating ES include climate and water regulation, soil erosion regulation, water purification, pollination, and regulation of pests and diseases (Millenium Ecosystem Assessment, 2005). Forage legumes can directly or indirectly affect these ES. For example, legume-soil microorganism nexus might reduce atmospheric N2 and minimize the need for N fertilizer application. This is important not only to reduce C emissions from the fertilizer industry and transportation sectors, but also to minimize nitrate leaching to the environment (Sollenberger et al., 2019). There are different ways legumes can reduce nitrate leaching. The first mechanism might be simply by helping to reduce application of readily available soluble N via fertilizer that might leach beyond the root zone and reach the groundwater. Although forage legumes reduce atmospheric N, and add N to the system, the N is recycled in slow-release forms such as litter deposition or root/nodules turnover (Dubeux et al., 2007). Nitrogen from livestock excreta often is lost via ammonia volatilization and denitrification, reducing the N pool that
Another mechanism might occur with arboreal legumes, where a deeper root system might recycle back to the soil surface nitrate that has passed beyond the surface horizon (0-20 cm) where most of the grass roots are (Chintu et al., 2004). Forage legumes might also enhance pollinator habitat (Garcia et al., 2019; Sollenberger et al., 2019) by providing more floral resources both in space and time. Forage legumes could also reduce soil erosion when used as cover crops or even used as windbreaks to reduce wind erosion, in the case of arboreal legumes (Garcia-Estringana et al., 2013; Wood et al., 2013). These examples of how legumes can provide essential regulating ES while intensifying livestock production illustrate well the key role of forage legumes in the SI of livestock systems.

Adoption of forage legumes
All these benefits highlighted for forage legumes will have a significant positive impact only if there is a greater adoption of these forages in livestock systems. Temperate legumes have been widely used in livestock systems, with *Trifolium* and *Medicago* sp. being perhaps the most adopted genera. In tropical and subtropical regions, however, adoption still needs to increase. Successful examples of adoption have occurred in different parts of the world, with greater adoption in Southeast Asia, Africa, and Australia (Shelton et al., 2005), with emerging options in Latin America (Boddey et al., 2020). Reasons for adoption include availability of seed supply at an affordable price, pioneer farmers, and most importantly, understanding from land managers about the advantages associated with adopting forage legumes.

Concluding remarks
Global population is rapidly increasing, and food supply must increase to follow demand. Animal food sources are key to ensure quality early-childhood development and sustain human progress. Intensive use of agricultural inputs and economic growth have been threatening global natural resources and ecosystems. In this scenario, forage legumes are key to develop sustainable livestock systems, increasing livestock production with reduced use of resources. Besides increasing livestock production with limited off-farm inputs, forage legumes deliver other ecosystem services that are beneficial for the entire society. These include enhanced pollinator habitat, biological N2 fixation and nutrient cycling, soil organic matter formation, and increase in net primary productivity. The future of forage legumes in the process of sustainable intensification depends on larger adoption worldwide. Demonstrated on-farm success and supportive governmental policies must be put in place to increase the adoption of forage legumes in livestock systems.

References


The importance of forage legume inclusion in agricultural swards to enhance earthworm activity and water infiltration rates

Shnel, A1,2; Tracy, S2; Schmidt, O2; Murphy, P2; Lynch, M.B1,3; Grace, C1,4; Boland, T.M1; Sheridan, H1.
1Teagasc Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork P61 C997.
2School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4 D04 V1W8.
3Teagasc Environment Research Centre, Johnstown Castle, Co. Wexford Y35 Y521.
4 Devenish Nutrition, Dowth Hall, Dowth, Co. Meath A92 T2T7.

Key words: Temperate grassland; legumes; water infiltration; earthworms.

Abstract

Increased grassland productivity in temperate regions has largely been achieved through perennial ryegrass Lolium perenne (PRG), coupled with large quantities of nitrogen fertiliser. However, the concern is growing regarding the negative implications of excessive dependence on nitrogen fertilisers. Research has demonstrated the benefits of legume inclusion on primary productivity. However, their potential to influence other processes is less well established.

Sampling was undertaken in autumn 2017 on twenty randomised plots representing five sward types, replicated four times. These had been established and managed by cutting since 2013. Sward types included: 1) PRG (250kg N ha⁻¹ yr⁻¹); 2) PRG; 3) PRG and white clover Trifolium repens; 4) 6 species mix comprised of PRG, timothy Phleum pratense, cocksfoot Dactylis glomerata, white clover, red clover Trifolium pratensis and greater birdsfoot trefoil Lotus pedunculatus; 5) species included in mix 4 with the addition of ribwort plantain Plantago lanceolate, chicory Cichorium intybus and yarrow Achillea millefolium. Mixes 2-5 inclusive received 90kg N ha⁻¹ yr⁻¹. Measurements included: soil bulk density, water infiltration rates, and estimated earthworm activity via surface cast counts.

Soil bulk density did not differ in response to sward type. However, the highest infiltration rates were recorded within the PRG and white clover swards, with an average of 29.7 (±3.5) mm hr⁻¹. In contrast, the lowest rates were recorded from the two PRG monocultures (2.43 (±0.5) and 4.2 (±1.2) mm hr⁻¹ for the 90 and 250 kg N ha⁻¹ yr⁻¹ swards respectively). Surface cast numbers differed significantly between sward types (P< 0.001). Numbers ranged from 127 (±7) casts m⁻² for PRG & white clover to 48 (±5) casts m⁻² for the PRG monocultures.

Our findings indicate the importance of legume inclusion within agricultural grasslands managed under reduced nitrogen fertiliser inputs for wider ecosystem service provision.

Introduction

Current reseeding advice and subsequent sward management and productivity in the Republic of Ireland, almost entirely revolves around perennial ryegrass Lolium perenne (PRG). Currently, this species accounts for 95% of forage grass seed sales per year (DAFM, 2018). PRG has many positive traits, including the ability to yield high levels of good quality forage and to recover quickly following defoliation. However, nitrogen (N) demanding grass quickly disappears from the sward when N levels become limiting (Sheridan et al., 2008). N inputs represent a high direct cost to farmers and contribute to wider environmental problems (Stark and Richards, 2008). In addition, there is increasing concern regarding the loss of biodiversity in these simplified swards on wider ecosystem functioning. The role of Trifolium repens and T. pratense when grown with grass alone, or with grass and forage herbs, in promoting sward productivity while reducing reliance on fertiliser nitrogen is well established.
(Grace et al., 2019; Moloney et al., 2020). This, together with their potential to address a range of other agronomically important challenges (see Lüscher et al., 2014), make their inclusion in agricultural grasslands key to enhancing resource use efficiency and addressing environmental concerns associated with fertiliser N dependence. However, their potential to facilitate the provision of a wider range of ecosystem services which may be equally important within agricultural grasslands has received less attention. This study aimed to investigate whether increasing plant species diversity within grassland swards to include legumes +/- forage herbs influenced earthworm activity, soil bulk density and water infiltration rates.

**Methods and Study Site**

This plot (1.95 x 10m) experiment consisting of 5 sward types replicated 4 times was established at UCD Lyons Farm (53°18´ N, 6°32´W) in 2013. Sward types were 1) PRG (250kg N ha⁻¹ yr⁻¹); 2) PRG; 3) PRG and white clover *Trifolium repens*; 4) a 6 species mix comprised of PRG, timothy *Phleum pratense*, cocksfoot *Dactylis glomerata*, white clover, red clover *Trifolium pratensis* and greater birdfoot trefoil *Lotus pedunculatus*; 5) a 9 species mix included the six species included in mix 4 with the addition of ribwort plantain *Plantago lanceolate*, chicory *Cichorium intybus* and yarrow *Achillea millefolium*. Mixes 2-5 inclusive received 90kg N ha⁻¹ yr⁻¹. Sward types are referred to hereinafter as 1) PRG250; 2) PRG90; 3) PRGWC, 4) Simple; 5) Complex.

A full description of plot establishment, site description and management details to 2016 are available in Grace et al. (2019). The data presented in this current paper were collected in 2017. Plots received no fertiliser in 2017. They were maintained by cutting with a mulching mower weekly from April to June 2017 and subsequently on an approximately 28-day basis until the end of the growing season. The botanical composition of the plots in 2016, before the commencement of the current study, is presented in Table 1

**Table 1: Actual species composition of sward types measured in 2016.**

<table>
<thead>
<tr>
<th>Sward types</th>
<th>ryegrass</th>
<th>timothy</th>
<th>cocksfoot</th>
<th>white clover</th>
<th>red clover</th>
<th>plantain</th>
<th>chicory</th>
<th>yarrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRG90</td>
<td>72.60%</td>
<td>0.1%</td>
<td>0.87%</td>
<td>24.65%</td>
<td>0%</td>
<td>0.02%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>(±4.31%)</td>
<td>(±0.07%)</td>
<td>(±0.46%)</td>
<td>(±5.21%)</td>
<td></td>
<td>(±0.02%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRG250</td>
<td>97.90%</td>
<td>0.25%</td>
<td>0.02%</td>
<td>1.62%</td>
<td>0%</td>
<td>0%</td>
<td>0.1%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>(±0.45%)</td>
<td>(±0.15%)</td>
<td>(±0.02%)</td>
<td>(±0.60%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRGWC</td>
<td>53.80%</td>
<td>0.02%</td>
<td>0.32%</td>
<td>45.7%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>(±0.65%)</td>
<td>(±0.02%)</td>
<td>(±0.32%)</td>
<td>(±0.76%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple</td>
<td>20.65%</td>
<td>3.02%</td>
<td>32.20%</td>
<td>29.07%</td>
<td>14.90%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>(±0.79%)</td>
<td>(±0.34%)</td>
<td>(±1.49%)</td>
<td>(±2.43%)</td>
<td>(±1.43%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex</td>
<td>18.30%</td>
<td>2.72%</td>
<td>31.40%</td>
<td>29.15%</td>
<td>16.45%</td>
<td>0.02%</td>
<td>1.62%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>(±0.73%)</td>
<td>(±0.63%)</td>
<td>(±1.98%)</td>
<td>(±3.36%)</td>
<td>(±2.26%)</td>
<td>(±0.02%)</td>
<td>(±0.83)</td>
<td></td>
</tr>
</tbody>
</table>

Three soil cores to a depth of 30cm were taken from each plot using a split corer with an inner diameter of 5cm (Eijkelkamp Agrisearch) in Feb-March (winter sample) and June-July (summer sample) 2017. Sampling was carried out when the soil moisture deficit for poorly drained soils was above -4 mm. Cores have located a minimum of 1m from each other and a minimum of 25cm from the plot edge. Cores were divided at 10 cm depth increments, and each 10 cm section was placed in a labelled aluminium tray (that was weighed beforehand) and fragmented into small pieces and dried at 105°C for 20 hours. Before weighing the soil, stones were removed by hand; their volume was recorded by immersing in water and measuring the change in volume. Stone volume was then subtracted from the total volume of the sample. Bulk density was calculated by dividing the dry soil mass by sample volume minus stone volume.

Water infiltration rates were measured across all plots in September 2017 using the double-ring infiltrometer method to measure the near-saturated hydraulic conductivity in the field (Bharati et al., 2002). Earthworm activity was accessed in the different sward types in October 2017. Ten days after the plots were cut, surface casts were counted using a 2500 cm² quadrat. Every cast in the quadrat was flagged to prevent double counts.
and ensure that all casts were counted. Casts with a diameter smaller than one cm were moved aside and only counted if an entrance hole to a burrow was seen. Counts from two randomly placed quadrats per plot were taken. Patches of white clover that had invaded the PRG plots (90kg N ha⁻¹ yr⁻¹) were avoided when all sampling was undertaken.

All data were analysed using ANOVA in R version 3.3.3 (R Core Team, 2017). Where more than one sample per plot was taken, a nested ANOVA was used to prevent pseudo replication. Tukey HSD tests were performed to check for significance between treatments. Significance was interpreted at the level of p<0.05. Generalised linear models (GLM) were selected to investigate the relationship between infiltration and the number of earthworm casts (log-transformed).

Results
Average bulk density ranged from 1.09 (±0.014) to 1.05 (±0.011) g cm⁻³ in the top 10 cm, and from 1.22 (±0.021) to 1.19 (±0.015) g cm⁻³ at a depth of 20 to 30 cm. In general, bulk density increased with depth (F₂,₂₃₈ = 91.26, P< 0.001).

Water infiltration rates differed significantly between sward types (F₄,₁₅ = 20.56, P< 0.001). The highest infiltration was recorded within PRGWC plots with an average of 29.7 (±3.5) mm hr⁻¹, followed by the complex and simple mixtures with 15.7 (±2.2) and 10.5 (±3.1) mm hr⁻¹ respectively, PRG90 and PRG250 had the lowest infiltration rates with 2.43 (±0.5) and 4.2 (±1.2) mm hr⁻¹ respectively. However, these did not differ significantly from the simple mixture (Figure 1).

It is interesting to note that when sward types were grouped according to functional groups, i.e., grass (G); grasses and legumes (GL); and grasses, legumes and herbs (GLH), sward types containing legumes didn’t significantly differ in their infiltration rates and had significantly higher infiltration rates than grass-only swards (Figure 1).

Figure 1: Variation in infiltration rates at near saturation hydraulic conductivity between sward types (left) and sward types grouped according to functional groups (right). Letters represent significant differences between treatments, P < 0.05 (left) and P < 0.01 (right) by Tukey’s post hoc testing. G= grass, GL = grass and legume, GLH = grass, legume and herb.

Surface cast numbers, used as a proxy for earthworm activity, differed significantly between sward types (F₄,₁₅ = 42.86, P< 0.001). Numbers ranged from 127 (±7) casts m⁻² for PRGWC to 48 (±5) casts m⁻² for PRG90 and PRG250, which in turn had significantly lower numbers of casts present compared to the three other sward types. The simple mixture didn’t differ significantly from PRGWC or complex sward types (Figure 2).

Similarly to the infiltration results, when sward types were grouped by plant functional group, swards containing legumes had significantly higher numbers of surface casts compared to grass only treatments (Figure 2). Regression analysis revealed a significant positive effect of earthworm activity on infiltration rates (P<0.001). At the plot level, surface cast numbers were found to explain 59.2% of the variation in infiltration rates (Figure 2).
Discussion

In this study, moderately diverse sward types had significantly higher infiltration rates and surface casts than the perennial ryegrass monocultures. It is likely that the inclusion of legumes indirectly increased infiltration rates (Fischer et al., 2014) by increasing earthworm activity (Schmidt et al., 2003; Fischer et al., 2014), thus increasing the proportion of macropores (Chan, 2004) open to preferential water flow during intense rainfall events. Increased water infiltration can translate into decreased surface runoff (Edwards et al., 1992) and can positively affect the soil’s water-holding capacity. Poorly drained, saturated soils will limit livestock and machinery trafficability on the farm, as they can cause severe damage to soil structure and increase compaction (Schulte et al., 2012), negatively affecting plant growth by reducing photosynthetic rates when soil conditions are anoxic (Laidlaw, 2009) and interfering with root growth (Tracy et al., 2012). Thus, in high rainfall areas (mean annual rainfall >1000 mm yr⁻¹), such as Ireland, increased infiltration rates could potentially translate to an increase in the number of available grazing days per season (Fitzgerald et al., 2008) and thus improved herbage production by allowing soils to dry faster. This could be particularly beneficial where soils have a high clay content.

Acknowledgements

The authors thank the Department of Agriculture, Food and the Marine (Ireland) for providing the funding to establish and manage the plots through the SmartGrass project via their Research Stimulus Fund. We also thank David Byrne, Gordon Kavanagh, Conor Bracken and Laura Gallego for their assistance with field work and Eugene Brennan for maintaining the plots.

References


Tree legumes as sustainable ecosystem services in livestock systems

Muir, J.P.¹; Cooper, C.E.²; Corriher-Olson, V.¹

¹ Texas A&M AgriLife Research & Extension, Texas USA; ²Texas Tech University, Texas USA

Key words: tree; arboreal; legumes; leguminous; ecosystem services

Abstract

Arboreal legumes provide multiple uses in pastures and rangelands. Trees directly and indirectly feed, house, doctor, and warm humans at minimal environmental cost through forage (fodder), timber, biofuel, medicines, as well as edible leaves, pods, and seeds. Leguminous trees, because they foster biological nitrogen fixation (BNF) and acquire deep-soil nutrients and moisture, compete less with herbaceous plants for shallow-horizon soil moisture and nutrients. Their ecosystem services (ES) are generally less obvious and quantifiable. These include converting CO₂ to sequestered C and released O₂ in N-poor soils where trees without BNF do not thrive. Other ES include shade for animals (including humans), plants, and soil microorganisms that would not otherwise survive in direct sunlight, in dry seasons, or under human mismanagement (overgrazing). Arboreal legumes in semi-arid and arid environments also provide habitat and nutrition to insects (pollinators), mammals, and birds during crucial drought seasons and years, facilitating repopulation to the ecosystem when rainfall returns. Additional ES include crucial ecosystem biological diversity, climatic stability, as well as aesthetic and cultural values. Humans have long recognized their value in natural semi-arid and arid ecosystems such as rangelands but have been slower to incorporate them into cultivated pastures where herbaceous monocultures dominate. Incorporating arboreal legumes with greater regularity into restored rangelands or cultivated pastures would not only increase overall productivity by adding non-herbaceous aerial and deep-soil root biomass but also provide ES that herbaceous species cannot match.

Introduction

We can no longer afford to manage grasslands solely for forage production leading to animal products that feed humanity. Arboreal legumes, especially in warm climates, can contribute to diverse ecosystem functions (Dubeux et al., 2017). Beyond fixing atmospheric C and N that translates into meat, milk, fiber and draught power, legume trees also provide ecosystems services (ES) that sustain environmental health and compensate for unsustainable crop and forestry production. We will review key ES that perennial, deep-rooted arboreal and shrub legumes provide in grasslands. We will then expand on potential approaches where trees and shrubs can provide additional environmental and human health benefits from natural and managed ecosystems where grasses predominate.

Arboreal legume ecosystem services

Atmospheric N₂ fixation: Industrial fertilizer N in agricultural systems is ultimately regulated by economic considerations and the presence of effective infrastructures for fertilizer production and distribution. The legume family (Leguminosae or Fabaceae) is the third largest family of flowering plants, with approximately 650 genera and nearly 20,000 species (Doyle 1994). Legumes often fix atmospheric N₂ that most plants cannot harness. Atmospheric N₂ can be fixed symbiotically by the association between Rhizobium species and legume roots. This represents a renewable source of N for agriculture (Peoples et al., 1995a, b). Including N₂-fixing legumes in livestock grazing systems cycles N into the soil as well as, via excreta from ruminants, thereby reducing industrial N fertilizer inputs with all their associated environmental issues.

Deep taproots: Deep-rooted arboreal trees can provide fodder year-round, especially during dry seasons and droughts, thereby sparing herbaceous layer overgrazing. Legume fodder trees are easier to grow in low-N soils, require little land, labor or capital, have numerous by-products and often supply feed within a year after planting. African
farmers have fed tree foliage to their livestock for centuries, using wild browse or trees that grow naturally on their lands (Le Houé 1980). Many farmers specifically grow fodder trees to feed their goats (Place et al., 2009) and studies confirm their significant impact on milk yields (Niang et al., 1996). Several other benefits of fodder shrubs, as cited by farmers, include the provision of products (firewood, stakes, bee forage and edible seed) and ES (fencing, soil fertility improvement, soil erosion control, and animal health and reproduction). Because of their high protein content, minerals and vitamins, and availability in dry seasons or droughts, fodder tree/shrub legumes have the capacity to complement crop residues and natural pastures. Being deep rooted, fodder trees are less affected by seasonal and yearly climatic variability, cycles and changes.

**Sequestering C into soil via root attrition and leaf litter**

Leguminous taproots, whether arboreal or herbaceous legumes, cycle deep-soil horizon nutrients back into livestock systems via fodder-manure-soil microorganism-plant interactions thereby reducing fertilizer requirements. As deep-soil roots and surface leaf litter decompose, they also contribute to soil organic matter build-up (Vetaas 1992). Besides raising cation exchange capacity that reduces surface and subsoil mineral and moisture losses, this soil component sequesters C, thereby mitigating harmful effects of gaseous C molecules such as CO₂ or CH₄

**Shade = temperature mitigation**

Heat stress in livestock reduces appetite, weight gains, milk production and breeding efficiency (Haun 1997; McDowell 1968). Ideal conditions for beef and dairy cattle include a temperature range between 7 and 25 °C (Henry et al., 2012). Leguminous trees on the grazing landscape have an advantage over barns and temporary structures because of the cooling effect that evapotranspiration provides, better ventilation and reduced reflection of sunlight rays (Karki and Goodman 2010). Arboreal legumes likewise mitigate soil surface temperatures which, in warm environments, can benefit soil water-retention and protect microorganism or soil seed banks (Vetaas 1992).

**Plant, microorganism, or animal diversity and refugia**

Tree legume growth form, physiological, and reproductive characteristics provide habitat and nutrition to a variety of insect, mammal, and bird species during critical drought periods. Lateral roots close to the soil surface capture shallow soil moisture, while tap roots access water deep within the soil profile (Ansley et al., 2014). Many woody legumes increase soil water uptake through reductions in tissue water potential and accumulation of osmotic substances. These characteristics support pollen, seed and leaf production during drought periods when herbaceous species are dormant (Fagg and Stewart 1994). Seed pods from woody legumes may provide a crucial food source for humans, wildlife, and livestock. Tree legumes are also highly attractive to a variety of generalist and specialist arthropods. Herbivorous insects utilize tree foliage, pollen, nectar, extra-floral nectaries, and pods as food resources. Other insects bore into the wood to deposit their larvae. Stands of woody legumes are preferred foraging sites for insectivorous mammals due to high arthropod abundance and richness (Hackett et al., 2013).

Leguminous trees foster a spatial mosaic of herbaceous composition and soil nutrient distribution under their canopies that is different than that beyond the canopy (Zhou et al., 2018; Ansley et al., 2019). Transitions from grasslands to savannas or woodlands result in alterations to primary production, litter inputs, and input chemistry, which subsequently change soil C and N storage and dynamics along with microbial composition and activity. woodland soils under tree legumes often have greater populations of gram-negative bacteria, while grassland soils have a greater abundance of gram-positive bacteria and actinobacteria (Creamer et al., 2016). Soil fungal communities differ under tree legumes compared to open grasslands as well (Hollister et al., 2010). Growth of some herbaceous species, especially C₃ species, benefits from the nutrient enrichment and ameliorating effects of the woody canopy on air and soil temperature. Mc Cleery et al., (2018) reported decreases in animal diversity when African savannah woody canopy cover was less than 10% or surpassed 65%. Reductions in animal diversity associated with homogenization of vegetation structure may indicate subsequent reductions in ecosystem stability, resilience, and services.

**Plant secondary compounds.**

Leguminous tree fodder, pods, and bark often contain plant secondary compounds containing useful environmental health benefits beyond simple feed for ruminants. Condensed tannins are the best known and are particularly abundant in shrubby and arboreal legumes (Tedesci et al., 2013). They provide environmental services not only by suppressing internal parasites and rumen methane emission, but also reducing the need
for pharmaceuticals that often have unintended negative environmental effects (Iglesias et al., 2006).

**Multiple uses (fuel, lumber, honey, pulses, leafy vegetables) contribute to human nutrition and reduce need to exploit more land.**

Tree legumes are well known for their multiple uses. Fuelwood and charcoal have been incorporated in bioenergy systems worldwide. Their wood is dense and has a high heating value (Fagg and Stewart 1994). Since most woody legumes are smaller trees or shrubs, they are not typically used for large-scale timber production. However, their hard and durable wood is valued for local furniture construction, flooring, beams, and fence posts. Leguminous trees yield numerous products that contribute directly to human nutrition, including honey, flour, and jelly (Fagg and Stewart 1994; Bovey 2016). The foliage of some species is eaten as a leafy vegetable. Leguminous trees also produce gums for food additives and in pharmaceuticals. Woody legumes have been used green manure in agroforestry systems producing cereal grains, pulses, vegetables, and forages (Viswanath et al., 2018).

**Enhancing arboreal legume ecosystem services in grasslands**

We hypothesize that arboreal legumes provide more ES in grasslands than currently recognized. We propose these, along with the ES already well documented, justify protecting leguminous trees in rangeland and or actively including them in cultivated pastures to enhance not only ruminant productivity but also ecosystem health, environmental resilience and, ultimately, human health benefits.

**Selective rangeland brush clearing**

By selectively thinning or clearing grasslands with excessive tree cover, thereby sparing arboreal and shrub legumes with fodder and ES potential, plant and animal diversity will be conserved (Lima et al., 2018). This may not be as straightforward as it seems. Indiscriminate herbicide application or bulldozing is far easier than removing only invasive or undesirable species in a savannah or pasture. It also requires an understanding of which tree species should be left and why. Even in areas dominated by undesirable legume species, some parcels should be left undisturbed for wildlife habitat and landscape heterogeneity (Park et al., 2012).

**Including multiple canopies**

Including multiple canopies in grasslands can increase forage production with positive effects on harvestable animal product (Muir et al., 2015). This in turn enhances a wide gamut of animal diversity, both domesticated and wild ruminants as well as those that simply augment ecosystem stability and resilience during climate fluctuations as well as human mismanagement.

**Include in cultivated pastures**

Including arboreal legumes in cultivated pastures can increase sunlight capture with consequent forage biomass production. Greater animal production follows, especially when multiple herbivore species are used to harvest vegetation diversity (Muir et al., 2015). This practice, however, is not a widespread management technique, especially in temperate regions.

**Maintain natives and avoid exotics**

Many landscapes, especially arid and semi-arid tropical and subtropical grasslands, have native arboreal legumes that can be protected and increased (Viswanath et al., 2018). Experience with invasive arboreal legumes around the world indicate that utilizing natives in restoration or production-enhancing interventions is generally beneficial because they avoid introducing disruptive invasive species selected for aggressive traits (Bradshaw et al., 2008). Sustainable management will avoid fostering native invasives (Ansley et al., 2019).

**References**


Legumes as a Strategy for Reducing Greenhouse Gas Emissions of Forage-livestock Systems

DiLorenzo, N.¹, Dubeux Jr, J. C. B.¹, Garcia, L.¹, Guevara, R. D.², Lagrange, S.², MacAdam, J.², and Villalba J. J.³

¹North Florida Research and Education Center, University of Florida, Marianna, FL 32446, USA; ²Department of Wildland Resources, and ³Department of Plant Soils and Climate, Utah State University, Logan, UT 84322, USA

Key words: legumes; greenhouse gas; methane emission; mitigation; grazing

Abstract

The incorporation of legumes into forage systems has been a widely adopted strategy to increase pasture productivity and forage nutritive value while reducing N inputs. Considering the population growth and the diminishing land resources for food production, the need to increase the food supply will have to be balanced with the environmental impact of these systems, particularly their carbon footprint. Enteric methane production represents the largest source of greenhouse gas emissions from livestock. Certain forage legumes have evolved secondary plant compounds, such as tannins and other polyphenols, which have been associated with reductions in enteric methane emissions. Studies were conducted at Utah State University (USU) and at the University of Florida, North Florida Research and Education Center (UF-NFREC) to assess in vivo methane emissions in grazing cattle using the SF6 tracer technique. At USU, cattle grazing pastures of Birdsfoot trefoil (Lotus corniculatus; BFT) emitted less methane per unit of dry matter consumed when compared with cattle fed a totally mixed ration (50% barley grain, 25% alfalfa hay, and 25% corn silage) in ad libitum amounts. However, emissions in cattle grazing BFT did not differ from those grazing the legume Cicer milkvetch (Astragalus cicer) or a traditional pasture-finishing system based on Meadow brome (Bromus riparius). At UF-NFREC, three livestock-forage systems were tested during three consecutive years to determine the effects of including the legume Rhizoma peanut (Arachis glabrata Benth.; BHR) in bahiagrass pastures (Paspalum notatum Flügge) fertilized (BH) or not (BHF) with N during the warm season. No differences were observed in methane emissions (gd⁻¹) or methane emission intensity. From the legumes grazed in these experiments, only BFT contains significant concentrations of tannins. Thus, the potential to mitigate livestock enteric methane emissions by grazing legumes appears to be directly related to the presence of tannins.

Introduction

The ability to convert fibre into high-value animal protein has always been the main advantage of ruminants and one of the ecosystem services of greater relevance in a growing global population and food demand.

However, enteric methane production is a necessary byproduct of these systems. As production increases to meet global demand, more pressure is placed on these systems to be more sustainable in terms of their carbon footprint. Most successful strategies proposed to decrease enteric methane involve daily feeding of additives or supplementation under confinement situations. In the U.S., the cow/calf sector contributes to 58% of the greenhouse gas emissions, with 61% attributed to enteric methane (Lupo et al., 2013). The cow/calf segment relies mostly on grazing, a common feature across diverse geographic regions. Thus, the beef production industry segment that relies mostly on grazing has the greatest contribution to greenhouse gas emissions and has the least available options for mitigation.

Feeding a tannin-rich diet has been associated with reductions in enteric methane emissions in ruminants (Hristov et al., 2013, Aboagye et al., 2018). Thus, incorporating legumes into beef/forage systems may be one of the few alternatives
to decrease enteric methane emissions under grazing conditions. We hypothesize that the inclusion of legumes in grazing pastures may decrease the carbon footprint of beef/forage systems, either by decreasing enteric methane emissions, increasing productivity of the system, or both. The objective of this study was to assess the effects of adding legumes to grazing systems in terms of animal and forage performance, and enteric methane emissions in two contrasting regions of the U.S.: the southeast coastal plains, and the western plains.

Methods and Study Site

1. Grazing Study at the University of Florida

The experiment was conducted at the University of Florida, North Florida Research and Education Center (NFREC) during the cool and warm seasons for three consecutive years (2016-2018). Therefore, only data from the warm seasons will be reported in this study.

Treatments consisted of three year-round forage systems, distributed in a randomized complete block design with three replicates for nine experimental units. The first system (Grass + N) included N-fertilized (112 kg N ha⁻¹ yr⁻¹) ‘Argentine’ bahiagrass (Paspalum notatum) pastures during the warm-season, overseeded with a mixture (56 kg ha⁻¹ of each) of FL 401 cereal rye (Secale cereal L.) and RAM oat (Avena sativa L.) during the cool-season with a second application of 112 kg N ha⁻¹ yr⁻¹. Total annual fertilization for this treatment was 224 kg N ha⁻¹ yr⁻¹. System 2 (Grass + clover) included unfertilized bahiagrass pastures during the warm-season, overseeded with a similar rye-oat mixture, plus a mixture of clovers: 16.8 kg ha⁻¹ of ‘Dixie’ crimson (Trifolium incarnatum L.), 6.7 kg ha⁻¹ of ‘Southern Belle’ red clover (Trifolium pretense L.), and 3.4 kg ha⁻¹ of ball clover (Trifolium nigrescens Viv.), fertilized with 34 kg N ha⁻¹ during the cool-season. System 3 (Grass + CL + RP) included ‘Ecoturf’ rhizoma peanut (Arachis glabrata B.) and bahiagrass pastures during the warm-season, overseeded with a similar rye-oat mixture and a mixture of clovers (14 kg ha⁻¹ of Dixie crimson, 5.5 kg ha⁻¹ of Southern Belle red, and 2.8 kg ha⁻¹ of ball clover) during the cool-season.

Methane emissions were measured on the two tester steers from each experimental unit (pasture) using the sulfur hexafluoride (SF6) tracer gas technique described by Johnson et al. (2007). In addition, as described by Pinares-Patiño et al. (2016), dry matter intake was measured. Total faecal excretion was calculated by the marker dilution technique using Cr2O3 and TiO2 as indigestible external markers, and in vitro digestibility was measured from composited hand-plucked samples from each pasture. Average daily gain (ADG) was determined by differences in animal weights at the beginning and end of each grazing season.

1. Grazing Study in Utah State University

Fifteen 2-year-old Angus heifers [541.09 kg BW ± 30 kg (Mean ± SD)] were randomly assigned to one of three treatment pastures: (1) Birdsfoot Trefoil, Lotus corniculatus (BFT), a tannin-containing legume; (2) Cicer Milkvetch, Astragalus cicer (CMV), a control non-bloating legume of similar nutritional and agricultural characteristics to BFT but without tannins; and (3) Meadow Brome, Bromus riparius (MB), a high-quality grass. Each treatment had 5 spatial replications (an experimental plot that represented the experimental unit of the design). Each replication was randomly divided into three paddocks (64 x 57m; 0.3648 ha), seeded with BFT, CMV and MB. One heifer was assigned to graze in each paddock (N=5 animals/pasture). Heifers were allowed to graze in one-twelfth of the paddocks, and they were moved to a new section every 3.5 days. Cows grazed their respective pastures for 77 days, during three sampling periods of 9 days each.

2. Confinement Study in Utah State University

Five 2-year-old Angus cows [2017 BW, 526.83 kg ± 18.71 kg; 2018 BW, 563.44 kg ± 83.61 kg (Mean ± SD)] were randomly assigned to individual adjacent pens (measuring 10 x 5 m) inside a covered barn to receive a TMR ration (25% of Alfalfa hay, 25% Corn silage and 50% Chopped barley).

The experiment was performed during two consecutive years, in two (2017) and three (2018) sampling periods of 9 days each. Enteric methane emissions and ADG were measured as described in Exp. 1. Intake was assessed through estimates of faecal output (using Cr2O3 as an external marker; Kolver et al., 1998) and digestibility (NIRS, AOAC,1990). In addition, urine samples were analyzed for urinary nitrogen contents and blood serum samples for urea nitrogen (BUN) (Lagrange et al., 2020).

Statistical analyses

Exp. 1 was analyzed as a randomized complete
block design using PROC Mixed of SAS (SAS Inst., Cary, NC), with treatment and season as fixed effects and block and year as random effects. For Exp. 2 and Exp. 3, response variables were analyzed as a split-plot design with repeated measures. In both experiments, cows (random factor) were the whole plot units with treatment (pasture species; ration) as a fixed factor and day, period and year (confinement experiment) as the repeated measures. The variance-covariance structure used was the one that yielded the lowest Bayesian information criterion.

Results

Exp. 1 - Grazing Study in the University of Florida

Methane emissions and emissions intensity are shown in Table 1. No effect of treatment \((P \geq 0.18)\) was observed on DMI, \(\text{CH}_4\) emissions, or methane emissions intensity.

Table 1: Dry matter intake (DMI) and enteric methane emissions from beef steers during the warm-season; 2016 to 2018.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>Grass+N</th>
<th>Grass+clover</th>
<th>Grass+CL+RP</th>
<th>SE²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI(^\text{1}), kg d(^{-1})</td>
<td></td>
<td>6.8</td>
<td>6.3</td>
<td>7.6</td>
<td>0.54</td>
<td>0.24</td>
</tr>
<tr>
<td>DMI(^\text{1}), as % of BW</td>
<td></td>
<td>1.79</td>
<td>1.67</td>
<td>2.04</td>
<td>0.150</td>
<td>0.25</td>
</tr>
<tr>
<td>(\text{CH}_4) g steer(^{-1}) d(^{-1})</td>
<td></td>
<td>117</td>
<td>113</td>
<td>101</td>
<td>24.8</td>
<td>0.90</td>
</tr>
<tr>
<td>(\text{CH}_4) BW(^{-0.75})</td>
<td></td>
<td>1.4</td>
<td>1.4</td>
<td>1.2</td>
<td>0.73</td>
<td>0.91</td>
</tr>
<tr>
<td>(\text{CH}_4) g ha(^{-1}) d(^{-1})</td>
<td></td>
<td>548</td>
<td>447</td>
<td>359</td>
<td>96.2</td>
<td>0.40</td>
</tr>
<tr>
<td>(\text{CH}_4) g kg of DMI(^{-1})</td>
<td></td>
<td>24.1</td>
<td>24.2</td>
<td>17.4</td>
<td>5.4</td>
<td>0.61</td>
</tr>
<tr>
<td>(\text{CH}_4) g kg of ADG(^{-1})</td>
<td></td>
<td>397</td>
<td>448</td>
<td>225</td>
<td>85.1</td>
<td>0.18</td>
</tr>
</tbody>
</table>

\(^{1}\) Grass+N = N-fertilized (112 kg N ha\(^{-1}\)) bahiagrass pastures; Grass+clover = unfertilized bahiagrass pastures; Grass+CL+RP = rhizoma peanut and bahiagrass pastures.

\(^{2}\) SE = Standard deviation from the observations in 3 consecutive years (2016, 2017 and 2018).

\(^{3}\) Dry matter intake was measured only during 2016 and 2017, using \(\text{Cr}_2\text{O}_3\) and \(\text{TiO}_2\) as fecal output markers.

Exp. 2 and Exp 3. - Grazing and Confinement Experiments in Utah State University

Cows grazing BFT (1.9% condensed tannins) showed greater weight gains than cows grazing CMV or MB \((P=0.0006)\), but similar to cows fed the TMR \((P=0.5790; \text{Table 2})\). Methane emissions per unit of intake from cows grazing BFT were lower than emissions from animals consuming the TMR \((P=0.074)\). Methane emissions were comparable among animals grazing CMV \((P=0.1180)\), MB \((P=0.6763)\) or fed the TMR (Table 1). Blood urea nitrogen concentrations were similar in cows grazing BFT or CMV \((P=0.1202)\), but greater than in animals grazing MB or consuming the TMR \((P=<.0001)\). Urinary nitrogen concentrations were similar among the diet treatments \((P=0.5266; \text{Table 2})\).
Table 2: Response variable by animals during Exp. 2 and 3. Means in a row with different letters (a-c) are significantly different at the α = 0.10. SEM: Standard error of the mean.

<table>
<thead>
<tr>
<th>Grazing Study</th>
<th>BFT</th>
<th>CMV</th>
<th>MB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>14.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.063</td>
<td>13.14&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>DMI/kg LBW</td>
<td>0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.010</td>
<td>0.12&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>DMI%BW</td>
<td>2.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.238</td>
<td>2.57&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Methane per day, g/d</td>
<td>283.56</td>
<td>13.254</td>
<td>261.37</td>
</tr>
<tr>
<td>Methane/kg DMI</td>
<td>20.55</td>
<td>2.119</td>
<td>21.04</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.079</td>
<td>0.18&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>BUN, mg/dL</td>
<td>17.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.748</td>
<td>20.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Urinary Nitrogen, g/L</td>
<td>4.55</td>
<td>0.536</td>
<td>4.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Confinement Study</th>
<th>Overall</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>10.87</td>
<td>0.362</td>
<td>7.97</td>
</tr>
<tr>
<td>DMI/LBW</td>
<td>0.08</td>
<td>0.003</td>
<td>0.07</td>
</tr>
<tr>
<td>DMI%BW</td>
<td>1.78</td>
<td>0.087</td>
<td>1.46&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Methane per day, g/d</td>
<td>224.69</td>
<td>12.464</td>
<td>253.09</td>
</tr>
<tr>
<td>Methane/kg DMI</td>
<td>28.87</td>
<td>1.966</td>
<td>32.52</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.81</td>
<td>0.069</td>
<td>0.73</td>
</tr>
<tr>
<td>BUN, mg/dL</td>
<td>7.06</td>
<td>0.748</td>
<td>-</td>
</tr>
<tr>
<td>Urinary Nitrogen, g/L</td>
<td>3.92</td>
<td>0.536</td>
<td>-</td>
</tr>
</tbody>
</table>

Discussion

In Exp. 1, despite the numeric reduction of nearly 44% in emissions intensity when including rhizoma peanut in the warm-season forages (397 vs 225 g of CH4 kg of ADG-1 for Grass+N and Grass+CL+RP, respectively; P = 0.18), no effects were observed in daily methane emissions. Most likely, the lack of effect on CH4 methane emissions observed in this experiment may be related to the fact that, unlike other tropical legumes, rhizoma peanut does not contain significant concentrations of tannins (Naumann et al., 2013).

Cows grazing a tannin-containing legume (BFT) showed greater weight gains than cows grazing a non-tannin containing legume (CMV) or a grass (MB), but similar to cows fed a confinement ration with high contents of roughage. This outcome may be explained by the high nutritional quality of BFT comparable to the high-roughage confinement ration. Moreover, tannins from BFT are responsible for increasing the efficiency of using dietary protein in the intestines (Mueller-Harvey et al., 2019). Therefore, the greater ADG observed for animals grazing BFT than for animals grazing MB could also be explained by the greater intakes by cows grazing BFT.

The lower methane emissions per unit of intake in cows grazing BFT vs cows consuming the high-forage TMR suggests a positive effect of condensed tannins or nutrients in BFT on methane abatement (Min et al., 2020). Blood urea nitrogen and urinary nitrogen concentrations were similar in cows grazing tannin- (BFT) or non-tannin (CMV) containing legumes, suggesting that tannins in BFT did not reduce ruminal proteolysis or shifted the site of nitrogen excretion from urine to faeces, as reported in previous studies (Lagrange et al., 2020), likely due to the low concentration of tannins (1.9%) in this legume. These results suggest grazing BFT is a viable alternative to high-roughage confinement rations for maintaining beef production with similar or potentially lower levels (i.e., methane emissions) of environmental impact.

In conclusion, the incorporation of tannin-containing legumes into grazing systems can decrease greenhouse gas emissions, reducing the overall carbon footprint of beef production.
References


THEME 3. LIVESTOCK PRODUCTION SYSTEMS

Topic: Sustainable Management of Grasslands/Rangelands Ecosystems
Short-term high-performance pastures in temperate eastern Australia

Rob Eccles

* RJ Eccles Agronomy & Agribusiness Services, PO Box 6161, St Lucia Qld, Australia 4067, robecles@bigpond.com

Key words: ryegrass; chicory; plantain; beef; sheep; rain-fed; grass-fed; gibberellic acid

Abstract
In exclusively rain-fed/grass-fed grazing systems, Short Term High-Performance Pastures (HPP) are used in specialised finishing paddocks to produce high-quality feed, enabling livestock to maximise their genetic production potential and meet market carcass specifications at the youngest age possible. This strategy not only achieves premium prices but also requires just 8% of a breeding enterprise’s land to finish animals. Described are the range of species choices and combinations used in different environments of the Australian Eastern high rainfall zone, the reasons these species are used and the options available to meet animal requirements strategically. Instead of a monoculture of fodder crops, combinations of short-term hybrid ryegrasses with annual clover species and forage herbs are utilised to ensure animals gain weight every day of the year. Details are given of the tools used to optimise plant production such as the timing of synthetic fertilizer, use of recycled organic material to reduce metabolic stress on animals, and plant growth regulators to boost plant growth. Explanations are given on how the HPP system is used to enhance grazing enterprises in the erratic climate of eastern Australia and to boost recovery from the catastrophic economic consequences of drought. Key performance indicators include weight gain per 100 mm rainfall and dry matter per unit of nitrogen. These measurements have caused a paradigm shift in managers’ thinking on what is important in profitable livestock enterprises and widening their focus beyond animal and plant genetics. Evidence and examples are given on the use of HPP to ensure that farm operators not only survive but thrive, taking profitable control of their livestock finishing enterprises.

Introduction
In eastern Australia, pasture types ranging from degraded native pastures, semi-improved pastures, sown and fertilized pastures, fodder crops and grain are utilised for meat production from grazing livestock, predominantly sheep and cattle. The evolution and use of short-term, high-performance pastures (HPP) to produce high-quality feed and livestock is described. The HPP system refers to a tailored mix of productive pasture species that replace traditional fodder crops such as oats, hybrid sorghum and brassicas in the temperate high rainfall zone (650-1350 mm rainfall per year) of Australia. The species used are fast establishing, can be successfully zero-till planted and respond quickly to high fertilizer inputs even from a low soil fertility starting point. The system commonly starts on a small area of a farm, but it can be scaled up rapidly as producers gain confidence, skill and income. Intensifying the inputs into pastures on a small area of a farm facilitates adoption and develops the management skills of producers. The advantages of HPP allow farms enterprises to recover from adversity caused by poor management, drought and periods of low commodity prices. HPP promote adoption, fill the normal autumn-winter and summer feed gaps, yield high weight gains, finish livestock to meet target specifications, and switch producer attitudes from a ‘survive’ to a ‘thrive’ mentality.

History and Methods of HPP
When Plant Breeder Rights came to Australasia in 1987, it enabled plant breeding companies to market many new pasture forage cultivars and species in Australia’s beef/sheep region, with a potential to improve animal performance. Two examples were hybrid tetraploid Italian ryegrass and chicory. These species provided many new traits to a farm operation including an extended
range of seasonal maturity, robustness, beneficial symbiotic *Epichloë* endophytes, low aftermath heading, improved digestibility, a lower bloat hazard and many more possibilities for seed mix combinations.

By the mid-1990s, a limited number of commercial graziers who ran their farms as a business. The advantages were a non-bloating feed system that gave high daily weight gains with a superior period of feed supply which enabled them to realise their animals’ productive genetic potential to meet market specifications at a younger age without any setback periods of weight loss. They were able to take control of which market to target their animals’ sale and were among the first farmers to consistently meet tighter carcass traits over the last 30 years. For many of them there was a financial advantage in being classified as “preferred suppliers” enabling them to sell directly to customers.

Short-term diploid Italian ryegrasses were initially used in pure swards in HPP for easy weed control and simplicity. By the year 2000, additional species were being used such as herbs like chicory and plantain plus clovers, along with a broader range of short-rotation hybrid ryegrasses. Thus, HPP was evolving into formulating tailored-made mixes to best suit a farm’s particular location and microclimates. Further tailoring allowed each paddock’s performance to be observed and measured to give specific feedback on weight gain potential now that most farms owned scales to weigh livestock. This strategy provided better individual animal performance, achieved more animal product per hectare annually and gave the ability to finish stock nearly every month of the year. Hence the name “Short-term High-Performance Pasture”.

Currently, a selection from a range of species and cultivars is used in formulating each HPP pasture mix. In the Tableland regions, regular components are short-term rotation grasses ranging from the earlier seasonal maturity of Italian ryegrass up to late flowering hybrids from the combined crossing of Italian ryegrass, late flowering Spanish perennial ryegrass ecotypes and meadow fescue. These are typically high in metabolisable energy and protein with high palatability leading to high daily animal intake. In softer environments, tetraploid versions of these cultivars are used. Chicory, well known for exceptional animal performance, is usually included for additional quality and summer production. Plantain is added to mixes in drier climates and for its winter activity. Legumes are generally added mostly for their contribution to feed quality and they offer some limited nitrogen fixation. These legumes are white and red clovers in cooler climates or in the hotter, drier climates annual clover species such as berseem, balansa, arrowleaf, subterranean and Persian clovers. One example of a sowing mix would be 20 kg/ha late flowering diploid hybrid ryegrass x meadow fescue cross, 5 kg/ha late flowering tetraploid Italian ryegrass, 1 kg/ha each of chicory and plantain, 2 kg/ha diploid red clover, and 1 kg each of white, balansa and Persian clovers.

**Results/Benchmarks/Guidelines**

By 2005, approximately 300 farmers had sown typically 5 to 20% of their farms to HPP. From the experience gained, a range of benchmarks were developed to incentivise and guide producers towards achievable targets.

**Fertilizer Inputs.** Fertilizer inputs are key to the successful performance of these pastures (Table 1). It is essential to match fertilizer inputs in advance of expected nutrient removal, as a plan to replace nutrients later results in a premature failure of a HPP. Often a paddock’s fertility when these programs start is not adequate and requires a capital application of fertilizer. Many first-time users do not recognise and understand that HPP are producing so much more dry matter (DM) than their regular pastures, and therefore need high rates of fertilisation. Failure to provide HPP with adequate fertility is the most common reason farmers choose not to repeat planting further HPP areas due to their early failure. Diligent attentive advice from agronomists is essential to prevent this happening.
Table 1. Expected DM production per mm of rainfall determined by fertilizer inputs.

<table>
<thead>
<tr>
<th>Level of fertilizer</th>
<th>DM produced/ha/mm rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>2-3 kg</td>
</tr>
<tr>
<td>Low or erratic</td>
<td>3-5 kg</td>
</tr>
<tr>
<td>High inputs</td>
<td>11-14 kg</td>
</tr>
</tbody>
</table>

Comprehensive soil testing is essential to understand the starting point of major nutrients, to anticipate secondary and trace nutrients deficiencies that appear once extra demand is placed on soil, and to ensure that soil pH is adjusted by liming if necessary, to pH_{Ca} 5.5. The secondary elements of calcium and magnesium should be generally corrected as indicated via soil tests. This aids in animal performance, soil structure and correcting the pH. Usually, the species are not too sensitive to pH, provided soils range between pH_{Ca} 5.0-7.0. Phosphorus (P) is commonly applied at a rate double a district’s standard practice on regular pastures. Base potassium (K) requirements are high, with HPP programs highlighting hidden soil deficiencies. Annual sulphur (S) requirements are 15-25 kg/ha. Trace element deficiencies are specific to soil types. The higher the productivity per hectare, the more often shortages occur. Typically, boron and zinc deficiencies are seen in the plants. In the livestock, deficiencies occur in selenium, zinc, cobalt and copper. Finally, for soil health, cobalt and molybdenum have been found to be of benefit to symbiotic microbes.

A strong nitrogen input is essential to the success of a HPP. It must be supplemented as the N fixed by the legume component of a mix is insufficient to cope with demand. The optimal amount of N to apply is a consideration of the total amount of DM produced each year, the current season, and how much N is likely to be returned through animal excretion. In a typical HPP, the annual minimum should be 150 kg N/ha, applied as small, split applications over each year for efficiency, continuity and animal health reasons. Since most HPP pastures are producing in excess of 12,000 kg DM/ha/yr with protein levels ranging from 15 to 28%, the strategic use of N applications has the following management principles:

- As HPP are generally first planted into a poor fertility base, sow with a fertilizer blend containing N as well as P, S and often K.
- Once the pasture has germinated and established, apply ~50 kg N/ha. As HPP are often zero-till planted into old pasture, N fertilizer must also compensate for the process of decaying organic matter.
- Apply N in late autumn, late winter, mid-late spring and the end of summer. This practice is continued until 8 weeks before the HPP is terminated.
- Apply 25 kg N/ha for every anticipated tonne of DM produced until the first spring and then reduce this to 15 kg N/ha thereafter due to N recycling.
- As the grass base comprises short rotation grasses, the mid-spring N application is essential for development of vegetative daughter tillers for these grasses to persist after each summer. Failure to do this risks an early end for the HPP due to the grasses producing predominately reproductive tillers which do not meet livestock feed demands so summer target carcass weights are not achieved.

Plant Growth Regulators. Response rates of 20-23 kg of DM for every additional kg of N applied can be achieved, except for winter when the response is only 12 kg and overall growth is slow. By applying gibberellic acid twice @ 12 g/ha 6 weeks apart or three times @ 8 g/ha 4 weeks apart during winter, results in pasture growth rates are similar to those achieved in early spring. Daily winter DM production is increased from 15-25 kg/ha to 65-90 kg/ha.

Animal Production. It is preferable to use the New Zealand approach of focusing on performance per hectare rather than that of individual animals. Simple comparative DM measurements do not truly reflect the effects of various pasture systems’ performance on animal feeding behaviour, feed conversion and utilisation of the feed on offer. Live weight gain per 100 mm of rainfall (Table 2) is a better benchmark.
These benchmarks work well with temperate species in rainfall between 700 and 1,500 mm/yr in the High Rainfall Zone of eastern Australia and worldwide. Based on data collected by more than 100 graziers, the HPP beef production of 75-120 kg live weight/ha/yr for every 100 mm of rainfall is superior to other pasture options. The range in HPP performance is due primarily to variations in regular rainfall and what type of short rotation grass the climate allows. The typical weight gain performance from pasture in the high rainfall zone of NSW is 29 kg/ha/yr for every 100 mm of rainfall, or 230 kg/ha/yr when receiving 800 mm/yr. In contrast, a HPP system in the same rainfall will achieve 760 kg/ha/yr. This comparison highlights its strategic value in a grazing enterprise.

Studies conducted on animal performance have generated typical outcomes in eastern Australia from well managed HPP systems of:

**Beef weight gain**
- 0.5-1.0 kg/head/day winter
- 1.5-2.0 kg/head/day spring and autumn
- 1.0-1.5 kg/head/day summer

**Prime lamb weight gain**
250-300 g/head/day – less lamb enterprises have used the system so no seasonal figures are available.

These typical weight gains illustrate that not only is the pasture productivity high, but also individual animal performance is high. HPP enable animals to fulfil their genetic potential and to reach market specifications at a younger age. The system aligns with the signals from Meat Standards Australia (MSA) that grades meat based on eating quality, permitting access to higher paying markets.

**Animal Health**
Before entering HPP finishing systems, the animal health treatments for the livestock are like any other new animal arrivals to farms or induction for feedlots. They are supplemented for trace element deficiencies, vaccinated and treated for internal and external parasites. These improve animal wellbeing giving the benefits of improved performance and a reduction in unwanted deaths.

Livestock can suffer metabolic disorders and sudden death when HHP’s are driven very hard with synthetic fertilizer inputs. There was a situation one year where a few farmers in one district were losing more than 5% of their animals over just a few months. An investigation showed high fertilizer N inputs lead to excessive crude protein, putting animals into an energy crisis as they tried to convert it into urea to excrete in their urine. Research showed that ryegrass species uptake of N is very rapid. Within 2 weeks of an application, it is mostly all in the plant tissue. On these farms, crude protein spiked as high as 33% in tissue tests during cloudy weather, leading to a significant drop in daily weight gain and the occasional death. Under the same conditions, the natural cyanide levels spiked in clovers leading to sudden animal deaths from heart failure. The solution to keeping to the required annual N input was to apply lesser amounts of N more frequently. Further improvements in animal performance and safety came when substituting synthetic fertilizer with animal manures and other recycled organic material such as composted food waste. These recycled organics are available at a reasonable cost in eastern Australia. They slowly release plant available nutrients to the HPP species and assist as a buffer for any later synthetic fertilizer applications. Using this strategy virtually ended any animal metabolic-related problems. Trials showed setting the recycled organics application rate to the annual P requirement satisfied all the annual major, secondary and trace nutrient demands except for N. As a bonus, it took the guesswork out of supplementing trace elements. Farmers still needed to apply 50% of the N demand as synthetics, but relative feed value tissue testing showed the danger had disappeared.

---

**Table 2: Typical beef weight gains.**

<table>
<thead>
<tr>
<th>Pasture type and fertilizer policy</th>
<th>Live weight gain/ha/100 mm rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native/natural pasture, zero inputs</td>
<td>5-15 kg</td>
</tr>
<tr>
<td>Native/natural pastures, superphosphate and legumes, low inputs</td>
<td>10-25 kg</td>
</tr>
<tr>
<td>Improved pasture, poorly managed, low inputs</td>
<td>20-35 kg</td>
</tr>
<tr>
<td>High input/improved pasture, well managed, optimal inputs</td>
<td>50-80 kg</td>
</tr>
<tr>
<td>High performance pasture (HPP system), optimal inputs</td>
<td>75-120 kg</td>
</tr>
</tbody>
</table>
**Weed Control and Insect Control**

Generally, weeds are not a major concern providing the established pasture populations are high. After establishment, weeds usually are absent from HPP pastures due to thick vigorous plant growth and grazing management. Species used in HPP are generally tolerant of insect attack. Usually, the insect pest problems are the same known ones specific to all pastures in a particular region, so weed and pest husbandry practises are as for other pastures.

**Grazing Management**

During establishment, grazing as early as possible without pulling the grass is critical. Early grazing firstly allows companion species to compete with the ryegrass and will assist in weed control.

A management area for each animal mob is created using some form of “pulse grazing” strategy. Ideally, there are at least four fenced grazing units exclusive to each mob. This can be four paddocks, or a single paddock subdivided into four by portable electric fencing. The short rotation grasses in a HPP can then be grazed for 1 week followed by 3 weeks of rest. This practice optimises DM production and allows enough sunlight for the other pasture species to flourish.

Grazing pressure will influence the persistence of these pastures. As the base short rotation grasses are usually hybridised ryegrasses in some form, the aims of grazing should be:

- Aim for a maximum pasture height of 15 cm (2800 kg DM/ha). Higher than this diminishes the digestibility and daily feed intake steadily.
- Ensure pasture post-grazing heights are always >5 cm (1200 kg DM/ha).
- De-stocking or reduced stocking is ideal at certain times when there is moisture stress – usually in summer. The simple goal is to not allow the grass to be grazed shorter than 5 cm or plant death will occur.
- Higher stocking rates, mulching or haymaking is required to maintain quality at certain times of the year – usually in the spring.

**General Management for Best Results**

- Monitor weed and insect pests and control when necessary.
- Monitor stock performance and health.
- Fertilize at strategic times. For example, apply nitrogen in mid-spring and late summer.
- Ensure the choice of animals grazing these pastures can gain weight.
- Ensure there is a clean water supply and not muddy dams or saline water.
- Fence where necessary to realise the full potential of the pasture. Electric break fencing is usually sufficient.
- Keep in close contact with a competent pasture technologist/agronomist for the day-to-day management and general advice.

**Summary of the Disadvantages**

- Graziers require a high degree of competency and quality advice in both grazing management and general agronomy.
- Animal performance is pushed hard and can lead to metabolic disorders and deaths.
- Although the seed sowing costs are only $20-$40 higher than a typical perennial-based pasture, the fertilizer inputs are considerably higher.
- The increased rate of animals achieving market specification requires adjustment in stock policy which can lead to greater capitalisation to purchase additional stock and the need to development new skills.

**Summary of the Advantages**

- Animals continually gain weight in all months of the year, including winter.
- Provides the opportunity to finish livestock out-of-season resulting in access to a broader range of markets and ability to capture price premiums.
- Only 8% of a breeding farm’s land area is required.
- Species used are easy to establish and are suitable for planting using zero-tillage.
- Species used are tolerant of moderate soil acidity and salinity.
- The combined formulation of the species reduces the possibility of bloat.
- After only 6 months, net returns are made and not the 6 years often quoted for long-term perennial grass-based pastures.

Compared to long term pasture options, HPP produce twice the DM/ha, and due to their higher quality and higher utilisation, they produce three
times the typical meat production/ha.
- They earn three times the typical gross margin/ha.
- They give higher cash-flows and faster turnover of traded livestock.
- They provide higher rainfall use efficiency.

Discussion
The Short-term High Performance Pasture system is achieving very high animal performance. The strategic advantage the HPP approach offers to a grazing operation is compelling. It supports the expectations and satisfaction of both the producers (setting and achieving production, economic and social goals) and consumers (improved supply, improved quality). As more is learnt about the compatibility of the commonly used species and cultivars in the system, there will be an increase in the range of climates these pastures can be utilised in and improvements in their productivity and longevity. There are good prospects for greater application of this strategy in Australia.

Acknowledgements
Valuable research and technical support received from individuals in the organisations of AgResearch, University of New England, PGG Wrightson Seeds Australia and New Zealand, Seed Force Australia and New Zealand, Incitec Pivot and Sumitomo. Des and Stuart Green plus the many other Australian farmers who contributed during the implementation of the strategy. Special thanks to Dr Ted Wolfe, Dr David Hume and Andrew Allsop for their comments on this paper.

References


A systematic review of ecological and production outcomes under rest-grazing systems

McDonald, S.E¹, Lawrence, R², Rader, R²

¹NSW Department of Primary Industries, Trangie Agricultural Research Centre, Trangie, NSW, 2823, Australia; ²University of New England, Armidale, NSW, 2351

Key words: grazing management; biodiversity; integration, land condition, livestock

Abstract

With increasing pressure on grazing lands worldwide, there is a growing need to balance sustainable management of livestock to meet food production and environmental impacts. Grazing management practices that incorporate planned rest periods between grazing events (RG) may simultaneously achieve ecological and production goals. We conducted a systematic review of global literature that compared ecological and production outcomes of RG systems with either continuously grazed (CG) or ungrazed (UG) areas. In addition, we evaluated the extent to which ecological and livestock production outcomes have been assessed simultaneously in these studies and identified future research needs. A large proportion of the literature reported no difference (neutral response) between the different management systems. However, where differences did occur, the response of biodiversity, land condition and livestock production metrics was more often positive under RG than CG. When RG was compared to UG areas, differences were predominantly positive for plant biodiversity metrics but negative for invertebrate biodiversity, ground cover and plant biomass. Only a small proportion of studies considered the effect of RG on both ecological and production outcomes simultaneously. An understanding of both ecological and production trade-offs associated with different grazing management strategies is essential to make informed decisions about best-management practices for joint production and ecological outcomes across the world’s grazing lands.

Introduction

Globally, the livestock sector is recognised as a key driver of land-use change and degradation (MA 2005; Steinfeld et al., 2006), and increasing global population and demands for food production are placing greater pressure on grazing lands (Tilman et al., 2001; Foley et al., 2005; Steinfeld et al., 2006). Livestock grazing managed for both ecological and production goals can provide an opportunity to improve land condition and biodiversity conservation across large areas without sacrificing important socio-economic requirements (Papanastasis 2009; Metera et al., 2010). Several authors in recent decades have called for greater communication, collaboration and integration between animal production research and ecological research to bridge these disciplinary silos (Jackson and Piper 1989; Watkinson and Ormerod 2001; Dorrrough et al., 2004; Vavra 2005; Fischer et al., 2006; Metera et al., 2010; Glamann et al., 2015). If we are to understand the potential for dual ecological and production outcomes under different management strategies, it is essential to address this knowledge gap.

Grazing practices that incorporate periods of planned rest are commonly promoted to avoid environmental degradation and improve productivity (Norton 1998a; Teague et al., 2008), but considerable debate exists around the benefits, or otherwise, of these grazing management systems (Briske et al., 2008; Teague et al., 2013). Previous reviews have generally concluded that there is little difference in outcomes for animal production (i.e., weight gain, production per unit area, reproductive success) or rangeland sustainability (i.e., maintenance of biomass or ground cover) between contrasting management systems (Gammon 1978; O’Reagain and Turner 1992; Holechek et al., 2000; Briske et al., 2008; Hawkins et al., 2017; Di Virgilio et al., 2019). Yet, recent meta-analyses indicate that alternative grazing systems that incorporate periods of rest, compared with continuously grazed or ungrazed areas, have the potential to achieve multiple objectives (e.g. McDonald et al., 2019). Here,
we examine how grazing systems that incorporate periods of rest from grazing (RG) compare with continuously grazed (CG) and ungrazed (UG) systems to determine the potential trade-offs between animal production, landscape condition and /or biodiversity. We also explore the extent to which research has considered both ecological and animal production effects of RG management simultaneously and identify research gaps and directions for future grazing management research.

Methods and Study Site
A systematic literature review was conducted using Scopus, returning articles from 1950 until November 2019. We searched for studies that compared RG systems with either CG or UG systems and examined the effects on above-ground biotic or animal production variables. Title, keywords and abstracts were searched for the terms (graz*) AND (*divers* OR biomass OR “carrying capacity” OR “weight gain” OR conserv* OR richness OR product* or “ground cover” OR groundcover OR “bare ground”) AND (various grazing system terms, McDonald et al., 2019).

We compiled all studies that reported either RG–CG contrasts or RG–UG contrasts. For each study, we recorded the geographical region in which the study was undertaken (Europe, Asia, Middle East, Africa, North America, South America and Australia/New Zealand), climatic zone (tropical, arid/semi-arid, temperate, cold) based on the Koppen–Geiger Climate Classification, and all above-ground biotic and animal production response variables reported for each study comparing RG–CG and RG–UG. For each response variable, the effect of RG relative to CG and UG treatments was recorded as either significantly greater (positive, $P \leq 0.05$), significantly lower (negative), or no difference (neutral). In addition, species composition was recorded as either a difference or no difference in composition between the grazing systems. When opposing or inconsistent trends were present across multiple contrasts, it was denoted as neutral. From this information, we calculated the proportion of studies conducted in different regions and climate zones and the proportion of RG–CG and RG–UG comparisons reporting a positive, negative or neutral response for each variable. Studies that reported on both biodiversity and animal production variables in the same paper were classified as ‘integrated’. We also considered the proportion of studies that reported on both animal production variables and additional landscape condition variables such as ground cover, biomass and plant species composition.

Overall, variables were grouped into 50 categories relating to different biodiversity (e.g., richness, diversity, evenness, abundance), livestock production (e.g., livestock weight gain, production per ha, pasture quality or products such as milk, meat and wool), and landscape condition metrics (e.g., ground cover, biomass, pasture height, plant composition). This review focuses on those variables that had been reported in at least 10 studies.

Results
Rest-grazing versus continuous grazing
In total, 280 studies comparing RG and CG systems were included in this review. Most studies were undertaken in North America (40%), followed by Australia/New Zealand (29%). A little more than half of the research (52% of studies) was conducted in temperate regions. Most remaining research was evenly split between arid (24%) and cold climates (22%). Very little comparative RG research had been conducted in the tropics (2%).

The most commonly reported response variables in studies comparing RG and CG were biomass (114 studies), plant composition (107), livestock weight gain (105), ground cover (54), animal production per area (47) and plant species richness (41). However, few studies reported mammal, reptile or bird biodiversity metrics or functional diversity.

A large proportion of studies comparing biodiversity, land condition, or production variables reported no difference or no consistent difference between RG and CG systems (Table 1). However, where differences were observed, more studies reported positive than negative responses under RG management. The exception was livestock weight gain, where 34% of studies reported a negative response under RG systems. While there was most often no difference in plant diversity metrics, the majority of studies (74%) reported a difference in plant composition between the two grazing treatments.

Rest-grazing versus ungrazed
One hundred nine (109) studies compared RG with UG areas. The majority of these studies were in arid or semi-arid environments (45% of studies), followed by temperate (30%) and cold (24%) climates. Again, very few (1%) studies have
been undertaken in tropical environments. Most research has been undertaken in North America (42% of studies), followed by Asia (18%) and Europe (16%).

While again, a large proportion of studies did not report a significant difference in response variables between management systems, where differences occurred for the plant biodiversity variables. They were more often positive under RG than UG (Table 1). In contrast, invertebrate richness, bird abundance, ground cover and biomass were more frequently negative than positive under RG. In addition, 75% of studies reported a difference in composition between RG and UG areas.

**Integration of biodiversity and livestock production research**

The majority (51%) of research comparing RG and CG reported animal production-related variables, while 32% reported the response of biodiversity variables. Only eight studies (<1%) examined both biodiversity and livestock production variables simultaneously. However, a greater proportion of studies (33%) examined livestock production variables alongside land condition variables.

**Table 1: Trends in response variables (percent of total papers) in studies that compared rest-grazing (RG) with continuous grazing (CG) and in studies that compared rest-grazing to ungrazed (UG) areas.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>RG – CG</th>
<th>RG – UG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negative (%)</td>
<td>Positive (%)</td>
</tr>
<tr>
<td>Plant richness</td>
<td>12 (5)</td>
<td>39 (16)</td>
</tr>
<tr>
<td>Plant evenness</td>
<td>0 (0)</td>
<td>40 (4)</td>
</tr>
<tr>
<td>Plant diversity</td>
<td>8 (2)</td>
<td>50 (13)</td>
</tr>
<tr>
<td>Bird abundance</td>
<td>17 (2)</td>
<td>33 (4)</td>
</tr>
<tr>
<td>Invertebrate abundance</td>
<td>20 (3)</td>
<td>47 (7)</td>
</tr>
<tr>
<td>Invertebrate richness</td>
<td>0 (0)</td>
<td>90 (9)</td>
</tr>
<tr>
<td>Total ground cover</td>
<td>4 (2)</td>
<td>59 (32)</td>
</tr>
<tr>
<td>Plant density/abundance</td>
<td>23 (3)</td>
<td>31 (4)</td>
</tr>
<tr>
<td>Sward height</td>
<td>0 (0)</td>
<td>63 (10)</td>
</tr>
<tr>
<td>Biomass</td>
<td>7 (8)</td>
<td>49 (56)</td>
</tr>
<tr>
<td>Specific plant species for livestock production</td>
<td>10 (2)</td>
<td>52 (11)</td>
</tr>
<tr>
<td>Pasture quality</td>
<td>13 (4)</td>
<td>33 (10)</td>
</tr>
<tr>
<td>Livestock weight gain</td>
<td>34 (36)</td>
<td>17 (18)</td>
</tr>
<tr>
<td>Livestock production per area</td>
<td>17 (8)</td>
<td>49 (23)</td>
</tr>
<tr>
<td>Other livestock products (milk, wool, meat)</td>
<td>10 (3)</td>
<td>32 (10)</td>
</tr>
<tr>
<td>Livestock health</td>
<td>9 (2)</td>
<td>27 (6)</td>
</tr>
</tbody>
</table>

**Discussion**

Consistent with previous reviews (O’Reagain and Turner 1992; Holechek et al., 2000; Briske et al., 2008, di Virgilio et al., 2019), a large proportion of studies found no difference, or no consistent difference in biodiversity, land condition or livestock production variables between RG and CG or UG areas. This agrees with previous conclusions that stocking rate is a greater driver of grazing impacts than grazing system (O’Reagan and Turner 1992, Ash and Stafford Smith 1996). Despite this finding, significant differences between grazing systems were reported in many studies. This, combined with the fact
that positive benefits of RG systems are widely promoted, highlights a need to understand better what is driving these differences and how positive effects can be achieved. Analysis by McDonald et al. (2019) indicated the relative length of rest and graze events can influence the response of some variables, with benefits generally observed with an increasing amount of rest relative to grazing time. Di Virgilio et al. (2019) also examined a number of potential explanatory factors, including livestock type, rangeland type, rainfall, grazing intensity, paddock size and study duration. However, few consistent effects were identified.

Differences between RG and CG were predominantly positive under RG for all biodiversity, land condition, and production variables, except livestock weight gain. This indicates the potential benefits of certain RG systems, and further research into how these benefits can be achieved is warranted. When compared with UG areas, RG had a predominantly positive effect on most plant biodiversity variables, but not invertebrate richness and bird abundance. However, land condition variables (plant density, sward height, biomass and ground cover) were lower under RG than UG. While this is to be expected under grazing, it indicates that despite the benefits of RG systems in comparison to CG management, greater attention is needed to reduce the impact of grazing on land condition. Most studies reported a difference in species composition between RG areas and CG or UG systems, highlighting the importance of investigating changes in composition that may not otherwise be detected using traditional richness and diversity measures.

Understanding the ecological and economic (production) trade-offs associated with different grazing management strategies is necessary to make informed decisions about best management practices (Metera et al., 2010). However, while over half of the studies examined livestock production variables, less than 1% of the total studies included in this review examined livestock production in conjunction with biodiversity variables. This highlights the need to improve communication and collaboration between ecological and agricultural production researchers to achieve ecological and animal production outcomes simultaneously in grazing lands, a goal that will become increasingly important as demand for food production increased biodiversity declines continue.

In conclusion, this review shows potential for RG systems to achieve greater biodiversity, land condition and production outcomes, and further research is needed to better understand how these can be attained. Most studies that have examined periods of planned rest are concentrated in North America, Australia/New Zealand, Europe and Asia. Comparatively, little research has been undertaken in South America or Africa and tropical environments. Greater research effort needs to be directed toward the impacts of grazing management systems on fauna and biodiversity metrics in conjunction with animal production outcomes.

Acknowledgements
We would like to thank Dr Warwick Badgery and Dr Yohannes Alemseged for their review and comments on earlier versions of this manuscript.

References


Restoring value to grassland initiative: to maintain the environmental and economic value of grasslands and to promote their social and cultural functions

Wedderburn, L1; Ickowicz, A2; Mauricio, R.M3; Quiroga Mendiola, M4; Blanchard, M2; Le Thi Thanh Huyen5; Hubert, B2; Lasseur, JF; Blanfort, V2; Müller, J-P2

1AgResearch, New Zealand; 2CIRAD - INRAE - SupAgro, Montpellier, - France; 3Universidade Federal de Sao Joao, Brazil; 4INTA IPAF NOA, Argentina, 5NIAS, Vietnam

Key words: grassland; multifunctionality; livestock

Abstract
The Global Agenda for Sustainable Livestock (GASL), a multi-stakeholder partnership started in 2013 includes nine action networks (ANs). The networks are the working engine of GASL and are tasked with implementing activities, reports, providing evidence, guidelines and information on good practices demonstrated by the livestock sector. This paper outlines the activities of the network AN2 “Restoring Value to Grassland”, the purpose of which is to “maintain, restore and enhance environmental and economic value of grasslands, while promoting their social and cultural functions globally”. Since 2014, AN2 workshops have been held annually with scientists and stakeholders from rangeland/grassland biomes in Latin America (Brazil, Uruguay, Argentina, Chile), the Mediterranean (France, North Africa), Sub-Saharan Africa, Highland and Continental Plateaux (Tibetan Plateau/Mongolia/ Atlas in Morocco), the mountainous regions of France, New Zealand and Vietnam, and the prairie area of Canada. A data base of 40 global grassland cases and a range of preferred practices have been compiled for these areas. A methodological framework is now available for assessing the contribution of grassland systems to multiple functions, along with the development of associated indicators that are aligned with the sustainable development goals (SDGs) - social, local development, production, economic and environmental. The framework has been built and tested using the global grassland cases. We present the results from three cases from Brazil, Vietnam and Argentina.

Introduction
Grassland/rangeland systems are a major feed source for livestock. Globally, livestock grazing systems (LGS) deliver a multitude of services to society. Wilson (1986), Landais et al., (1987), Veiga and Tourrand (2003) demonstrated the importance of livestock in small farming agriculture through diverse and complementary roles. Alary et al., (2011) also documented a synthesis about the diversity of roles and functions of livestock including the important environmental contributions of LGS on several natural and anthropic ecosystems and these roles/functions are further highlighted by Gerber et al., (2013) and Dong et al., (2016). Raising an awareness of the contributions and functions delivered by the livestock sector is the focus of the Global Agenda for Sustainable Livestock (GASL). Formed in 2010, GASL is a partnership of sector stakeholders committed to the sustainable development of global livestock activities. GASL addresses global food security and health; equity and growth; resources and climate, while recognising the important contribution of the livestock sector to the SDGs of the UN Agenda 2030. Actions related to system analysis, development of good practice; implementation and documenting/communicating specific experiences and recommendations are undertaken by nine Action Networks (ANs). Outputs from Multi-Stakeholder Partnership (MSP) and AN meetings are used to foster regional and global dialogues, collect evidence, and inform policy and practice to document and develop livestock’s contribution to achieve the SDGs. The objective of this paper is to describe the work undertaken by Action Network 2 (AN2): “Restoring the Value to Grasslands”.

Materials and Methods
The Goal of AN2 is to maintain, restore and enhance the environmental and economic values of grasslands, while promoting their social and
cultural functions at the regional and global levels. The participants of the AN2 network enable access to contrasting rangeland/grassland biomes and their local communities, including Latin America (Brazil, Uruguay, Argentina, Chile), the Mediterranean (France, North Africa), Sub-Saharan Africa, Highlands and Continental Plateaux (Tibetan Plateau/Mongolia/Atlas - Morocco), the mountainous regions of France, New Zealand and Vietnam, and the prairies of Canada. Participants employ and share a range of methodologies when working with stakeholders using a participatory approach that leads to collective design of shared outputs.

Results
A framework for assessing the contribution of livestock grazing systems (LGS) to multiple functions aligned with the SDGs is under development. A variety of participatory methods to explore LGS through differing stakeholder perspectives are used, including, ontology workshops with researchers, semi structured interviews with farmers, videos and theatre forum. The framework consists of four dimensions with their associated indicators: productive, social, local development and environmental. The three following cases are outlined to illustrate the framework and explore its use.

**Brazil:** Natural regeneration of native trees for the implementation of a silvopastoral system for beef cattle production. This case demonstrates the potential to reconcile cattle production, environmental protection and social improvements in the tropics by using the silvopastoral system - trees, shrubs and forages (SPS). The following explains the findings of the contribution of the silvopastoral system on the dimensions of the framework. Social dimension: the higher biomass produced in the SPS secures cattle nutrition and offers financial stability to the farmer. These positive outcomes have corresponding flow on benefits to the farm worker families and local community, contributing to improved social security. Economic dimension – SPS enables the ability to carry more stock throughout the year with greater beef production per hectare, also providing opportunities for economic diversification (e.g., wood, carbon and tourism) compared to monoculture forage systems. Local development dimension: the farm is used as a demonstration site that several local technicians, extensionists and famers visit and learn collectively about the benefits of SPS and are inspired to adopt the principles. This extensions activity, demonstrating the multiple functions derived from SPS, is a key supporting element in increasing sustainable livestock production and consequently local development. Environmental dimension – the environmental benefits generated by SPS include higher biodiversity that provides the servicing function of biological control of insects and enrichment of fauna and flora; increased carbon sequestration by trees, and provision of natural sources of organic matter, phosphorus and potassium that reduce the need to use chemical fertilizer for associated grasses. The system is also animal welfare friendly through the provision of shade from trees.

**Vietnam:** In the mountains of Northwest Vietnam, the smallholder livestock farms depend largely on natural pastures for animal feed. Livestock grazing systems are considered insufficiently intensive to meet production challenges and provide enough income, and therefore they remain weakly supported by local government. This study has quantified the multiple contributions of these grazing systems to the sustainable development of farms and territories. Social dimension: Although consumers show a preference for meat from these grazing systems, the products from these systems have not been differentiated nor marketed. Pasture systems support 66% of farm workers. Economic dimension: In the Quai Nua commune region studied, livestock grazing systems produce about 49% of the meat production and about 48% of the meat integrated into the beef value chain (fresh meat, dried meat, meal). Local development dimension: 11% of the profits of actors in the beef value chain (collector, slaughter man, chef, and processor) are directly linked to the grazing systems. Environmental dimension: Livestock grazing systems support organic fertility and production of crop lands, with about 18% of the manure produced at communal level. Grasslands, essential for animal feed, contribute significantly to meat production, job creation, income and profits along the beef value chain. It seems necessary to ensure a visible, logical and sustainable approach to the management of grasslands to support animal production and the sustainable development of territories where livestock grazing systems are part.

**Puna North in Western Argentina:** These grasslands are in arid and semiarid environments that receive low and variable rainfall (100 to 300 mm/year). The Puna (3,500 m asl) is a plateau with a dry and windy climate and high temperature amplitudes, sparse vegetation and limited possibilities for agriculture. Three scales of analysis exist: the domestic unit, the community and the region. This case reports on the domestic unit as field data was available at this scale. The dimensions of the framework applied include the
**Economic dimension:**

The main products are llama meat and sheep or goat meat: 330 t and 200 t (carcass weight equivalent) respectively per year in the highlands of Jujuy province (Argentina). The meat is sold mainly in the local (formal and informal) markets. Indicators used include production (kg meat per year/farmer), value (kg meat sold per year/farmer) and the number of species/herd (diversity of livestock/farmer) the latter as an indicator of resilience capability. **Social dimension:** indicators used are related to the fragility of the domestic unit and the strength of local organizations. We selected a few local organizations involved in the local meat market where the domestic unit (which is the productive unit) is involved. The number of family members that live, work and exit the domestic unit are measures of its robustness or fragility. **Local Development Dimension:** At the family manager unit level, we identified several main problems with infrastructure (land tenure, roads, slaughter facilities, water availability and communication); scarce market and price information; and a scarce set of appropriate rules and laws for this type of production. The indicators selected were annual income (meat sold) and the number and diversity of marketing channels for the local meat produced. **Environmental dimension:** One of the most important issues in this dimension was the availability of parameters to measure transformations in the state of the natural resource. We plan to collect data that includes plant cover, diversity and richness and soil quality (organic matter, water storage capacity). This approach has allowed the research team to organise its dialogue and understand the importance of working across many disciplines and to change how we look at the world to see complexity, discuss ideas and methods, and to undertake participatory reflections.

**Discussion**

The sustainable development of LGS is a priority due to the economic, social and environmental relevance of livestock in the world. The promotion of sustainable alternatives requires a better understanding of livestock grazing socio-ecological systems, mainly their values and roles at a local level to global scale. However, LGS are complex systems and in order to identify effective interventions, a holistic understanding of system components and behaviours is required. Due to the huge diversity of rangeland contexts (from arid to wet biomes and from highlands to lowlands) and the numerous functions of livestock in these diverse contexts, it is not easy to have a generic representation. That is why it is so important to hear the voice of all of those participating in and influencing livestock grazed derived food systems. The framework provides a means of organising thinking and taking a holistic approach, but it is the social process that the framework enables that participants in AN2 have found most useful. Much time has been spent listening to each other’s world view and those of stakeholders to find a common language. These processes take time and are context specific. The ability to test the approach in real world situations has been helpful to create a shared set of indicators and to test the utility of the approach in diverse circumstances, to date it appears robust. The use of a framework that includes all four dimensions and associated indicators was helpful in demonstrating the contribution of livestock grazing systems to multiple functions simultaneously. The framework enables: making transparent the multiple values and challenges delivered from grassland livestock systems; identifying the trade-offs when seeking to optimize one value over another and use as a learning tool with multiple stakeholders and to provide a narrative for society to gain greater awareness of grassland systems and their multiple functionalities.

**Acknowledgements**

CIRAD, AgResearch, French minister, UFSJ, INTA IPAF NOA (Tomás Vera, Belén Quiroga Mendiola, María Celia Vittar, Juan Quiroga Roger) and Puna of NW Argentina communities.

**References**


Revisiting the reciprocity of human-ecological systems: Integrating extensive agriculture and transhumant pastoralism in the Northern states of India

Malhotra, Aayushi1; Nandigama, Sailaja2.

1Department of Humanities and Social Sciences, BITS PILANI, Pilani, Rajasthan, India
2Department of Humanities and Social Sciences, BITS PILANI, Pilani, Rajasthan, India

Keywords: Integrated peasant-pastoral production system; Reciprocity; Resource-dependent communities; Socio-ecological challenges

Abstract

India’s primary sector is characterised by the age-old practices of agriculture and pastoralism that have traditionally remained symbiotic. However, these relationships are dwindling in the light of uneven development focus and increasing climatic hazards. The current model of local development practices directly affects the overall environment while simultaneously increasing the vulnerability of the resource-dependent communities. Pastoralism, along with the agricultural enterprise that is expanding with the support of an irrigation network, is recognised as a major community-based occupation in the northern region of India. Despite that, pastoralism remains highly neglected in policy circles, whereas agriculture remains the dominant livelihood source both in popular imagination and development planning. In such a scenario, the contributions of pastoralism to rural livelihoods remain undervalued and scantily discussed in the context of the Indian subcontinent.

Highlighting the emerging need for sustainable management of natural resources amidst pressing climate crises, we recently focused on the significance of pastoralism in the region in the current paper. We emphasise integrating crop-livestock production systems based on the traditional reciprocities observed among the transhumant pastoral and settled agricultural communities in the North Indian states. While reviewing the interdependence and practices of exchange between these communities, we conceptualise the complex human-ecological requirements that serve as a basis for such long-lasting associations. It majorly includes exchanging resources, knowledge, market and labour, and persevering socio-cultural linkages. Based on such thematic understanding, we aim to highlight the need for a revival of an integrated peasant-pastoral production system that carries an untapped potential for managing the emerging socio-ecological challenges by promoting sustainable sharing of resources between the two co-dependent communities.

Introduction

India has a rich history of pastoralism, but it remains under-represented in the public domain compared to the livelihoods co-dependent on it and has co-evolved simultaneously. Pastoralism in all its forms (nomadic, transhumant, agro-pastoralism) remains an age-old livelihood strategy that did not receive the due attention and acknowledgement it deserves for its socio-ecological contributions (Mukherji et al., 2016; V. P. Sharma et al., 2003). As a production system, pastoralism remains highly entangled with the agricultural sector and changes the cultivation processes. However, the functional proximity and reciprocity embedded in the resource dependence make these two systems co-produce each other. This results from incompatible behaviour on the one hand and conflict on the other. Compatibility manifests in the exchange of products and services obtained from discrete production processes and networks of social relationships. Whereas conflicts are results of shared ecology, including landscapes for grazing and other natural resources. Many studies (Agrawal, 1991, 1993, 1994; Agrawal & Saberwal, 2004; Bhasin, 2013; Bhattacharya, 2019a, 2019b; Deb, 2015; Kavoori, 2005; Köhler-Rollefson, 1994; Saberwal, 1996; V. P. Sharma et al., 2003) document these complex relationships between farmers and pastoralists in India and provide the details on how reciprocity and conflict have remained a part of farmer-pastoral interactions since times immemorial.
Over the last few decades, with the phenomenal agricultural expansion, the reciprocal nature of these relationships has seen gradual and qualitative deterioration (Agrawal & Saberwal, 2004; Kavoori, 2005; A. Sharma, 2011). As a result, conflicts are rising, while compatibility seems to be on a slippery slope. Many factors promote this shift, but the lopsided development in the agricultural sector remains a significant one. Moreover, it has contributed to the marginalisation of the pastoralist communities by strengthening the existing exclusion policies that have continued since colonial times (Bhattacharya, 2019b; Chakravarty-Kaul, 1998). Thus, declining reciprocity between agriculture and pastoralism simultaneously increases the vulnerability of pastoral livelihoods.

Interestingly, different studies worldwide provide promising evidence of pastoralism being an ecologically and economically viable occupation in times of emerging climate crisis. These studies represent the emergence of an international sentiment towards pastoralisms revitalisation (Bayer & Waters-Bayer, 1989; UNEP & IUCN, 2015). They also call for promoting climate-friendly and integrated farming practices where a combination of crop-livestock production with minimal external inputs can be achieved (Breu et al., 2015; Deb, 2015). Considering such a dynamic shift at the international level, planned integration and revival of reciprocities between the existing migratory pastoralism and extensive agricultural practices in the Himalayan region need to be revisited. This could lead to sustainable outcomes and efficient land-use practices by both the communities in the long run. However, this process cannot be done in isolation and requires a holistic policy approach that considers the co-dependence and complementarity of these production systems in both human and ecological terms. Considering this potential opportunity, in this paper, we assess the traditional relationships between migratory pastoralism and agricultural practices within India’s northern states to understand the prospects of achieving the much-needed integration and revival of reciprocity between the peasant-pastoral communities.

Methods and Study Site

This paper is an outcome of a thematic analysis of the available literature that traces the co-evolution of agriculture and pastoral practices in the northern states of India. In this paper, we snowball the relevant literature focusing majorly on the pastoral communities in Himachal Pradesh, Uttarakhand, Rajasthan, Haryana, Punjab, Uttar Pradesh and Union territories of Jammu and Kashmir and Ladakh. In addition, an ongoing ethnographic study among the Gaddi pastoral community from the north Indian Himalayan state of Himachal Pradesh also contributes important insights to this paper. Various examples of traditional arrangements of symbiotic reciprocity between the pastoral and agricultural communities are arranged thematically to fill the knowledge gap identified earlier and provide a theoretical input that further strengthens the demand for a revision in the development policy meant for these sections of the society. The revival of reciprocity through farmer-pastoral co-dependency seems to hold the potential to manage the threats that loom large over the marginalised livelihood practices such as migratory pastoralism.

Symbiotic Reciprocities and other interactions

Many agricultural and pastoral communities (in states of Jammu and Kashmir, Ladakh, Himachal Pradesh, Haryana, Punjab, Rajasthan, Uttarakhand, and Uttar Pradesh) have remained in close alliance with each other for generations across these state boundaries. Traditional pastoral communities, including Bakarwals, Gujjars, Gaddis, Bhotias, Raikas and Rebaris, rear a variety of livestock and follow nomadic or transhumant migration patterns, interact with the settled farming communities on their migratory routes annually. Various studies provide the details of these relationships based on resource sharing pattern, seasonal market avenues, labour exchange and social and symbiotic reciprocity (Agrawal, 1993; Bhasin, 2013; Gooch, 2009; Kavoori, 2005; Köhler-Rollefson, 1994; Mukherji et al., 2016; Nautiyal et al., 2003; Nusrat, 2011; Rao, 2002; Saberwal, 1996). These studies also highlight the transitioning peasant-pastoral relationships that remain integral for achieving the much-needed sustainable outcomes in the face of increasing climate uncertainties. An in-depth and contextual understanding of all these distinct yet overlapping domains of reciprocity presented below provides for a strong argument to revisit the farmer-pastoral relationships to achieve sustainable production systems and promote an ecological equilibrium. This is done to provide a knowledge base to policymakers and practitioners for later use.

Resource-based reciprocity

The land is the primary resource for agriculture and pastoralism for maintaining their production system. Traditionally, these communities enjoyed mutual understanding and co-dependence where productive resources were shared and regulated according to seasonal needs. Farmers welcomed migratory pastoralists and their herds to obtain the nutrient-rich manure for their fields. In return,
pastoralists secured the forage for their livestock in the form of agricultural residue. Farm-pastoral exchange took place through the crop cycles and the fallow periods between harvests, as they suited the pastoralists’ migration cycle. For instance, Raikas from the western tracts of Rajasthan move up with their livestock in the summer months to Uttar Pradesh to obtain the forage from newly harvested winter crops (Agrawal, 1992; P. Sharma & Sharma, 2015). Likewise, Himalayan transhumant pastoralists, including Gaddis and Gujjars, move with their livestock to the lower plains in winter months when the higher pastures remain covered in snow (Bhasin, 2013; Gooch, 1992). The agricultural cycles in these terrains continuously provided the opportunity for reproducing this reciprocity while aiding pastoral mobility and access to grazing land and other productive resources. Livestock manure also offered a valuable organic resource that ensured soil fertility for a long time and provided a better yield of crops to the farmers in the plains (Agrawal, 1992; Agrawal & Saberwal, 2004). In exchange for livestock manure, pastoralists also received cash payments from the agriculturalists, which has drastically reduced over time (P. Sharma & Sharma, 2015). Many factors, including the introduction of irrigation technology, usage of inorganic chemical fertilisers, changed crop cycles and use of GMO seeds, burning of stubble, fencing of agricultural fields, fruit tree plantations as well as the increasing governmental support for intensifying commercial agriculture, have been found to impact the dwindling reciprocity between the two communities severely. Expanding agricultural enterprise in the region has overtaken even the wastelands and other marginal resources available for the pastoralists, affecting the traditional resource sharing mechanisms between the communities (Source: Primary data collected by authors on the Gaddi pastoralists in 2019).

Knowledge-based reciprocity

Agriculture and pastoral practices require different sets of knowledge for managing their resources and products through different means. Although animal husbandry has mostly remained a part of farming practices in north India, pastoralists acquired expertise in understanding animal behaviour, care practices, reproduction patterns and feeding needs, etc. Similarly, agriculturalists remain proficient in cultivation related and land use related knowledge. Farmer-pastoral interactions in the traditional resource sharing arrangements helped both exchange crucial information on each other’s production systems. This reciprocity was integral for enhancing productivity in both agricultural and livestock systems and was a valuable addition to their socio-ecological relationship and resource-sharing arrangements. In addition, the ecological knowledge that the pastoralists gather through their peripatetic experiences, whether in terms of biodiversity, health care practices and expert knowledge on climatic conditions, provided for valuable exchange with the farmer community. Farmer pastoral reciprocity thus served as an opportunity to understand the variability and transitions occurring across these production systems and exchange specialised and experiential knowledge.

Market and labour-based reciprocity

Seasonal farmer-pastoral interactions also open the exchange of products and labour across the two systems. Traditionally, pastoralists provide manure for the fallow fields and their labour to the agriculturalists for harvesting the standing crop. In such a manner, an increase in farm labour substantially helped the farmers on the one hand, and on the other, it provided pastoralists with the much-needed extra income or grains required for their consumption. Many settled agriculturalists even entrusted the pastoralists with their livestock for short term migrations. Pastoralists then would migrate with the extended herds that earned them monetary gains apart from direct exchanges. Other pastoral products, including wool, milk and dairy items, also found the marketing avenues in these interactions. This material exchange held cultural and ecological value for both the communities. The exchanged articles were specialised products that could only be found or produced in limited quantities and challenging ecological conditions.

Socio-cultural reciprocity

Farmer-pastoral interactions are not merely economic or ecological but also encompass many other socio-cultural dimensions. For instance, folding the animals on influential agriculturalist’s fields provided a sense of security to the Raika pastoral herds by keeping away local miscreants and preventing thefts on migration routes (Agrawal, 1992). The web of social networks developed across the communities through their symbiotic reciprocity resulted in building rich social capital and relations that often turned into fictitious kinships in practice. Bhasin (2013), in her paper on pastoralists of Himalayas, mention the “Dharam-bhais or pledge brothers” among the Gaddis of Himachal Pradesh. Such pseudo-kinship bonds developed out of these reciprocal associations went far beyond the economic exchanges that happened in functional terms.
Discussion

Despite being an age-old practice, pastoralism in the North Indian region has mostly remained out of the immediate focus of agrarian development models (Kavoori, 2005) undertaken by the state. As a result, the pastoral practices and their relationship with the agricultural production systems have not received the due attention they deserve. In the sections mentioned above and the themes identified from our systematic literature review, we highlight the areas of reciprocity between the agricultural and migratory pastoral systems across the north Indian terrain. This reciprocity that existed for ages has demonstrated closed production cycles (Breu et al., 2015) characterised by minimum wastage and minimum external inputs. However, over the past few years, these traditional relationships have weakened in the face of drastic change in the pattern of agricultural production and the prevailing development interventions that marginalise pastoralism as a lifestyle and occupation in more than one way. Moreover, decreasing the dependency of farmers on pastoralists has increased the latter’s difficulties by pushing them further to the margins and increasing their livelihood vulnerability more than ever. As a result, pastoral practices and the socio-ecological equilibrium they contribute to are dwindling.

Disruption in reciprocity processes between the regional pastoral and agricultural systems has directly affected the pastoralists and has left a latent impact on farming practices that are gradually becoming unsustainable and resource intense. Many scientific studies across the geography have established the significance of migratory pastoralism in maintaining food security and biodiversity, providing consumer goods and livelihoods by exploiting the marginal environments and agricultural residues (Bhasin, 2013; Breu et al., 2015; P. Sharma & Sharma, 2015). In such a scenario, when the dire consequences of Anthropocene are frequently felt through the fast-emerging climate crises, reviving the traditional practices of reciprocity, promoting resource sharing instead of segregation, and enhancing cooperation instead of isolation are much required. A renewed stress on reviving the moral economy through appropriate policy interventions that consider holistic development approaches, multiple stakeholder engagements, diverse livelihoods and a dynamic feedback system is needed to reinstate traditional practices and reciprocities.

As discussed throughout the paper, both agricultural and pastoral practices remain integral for several communities’ livelihoods and for pursuing ecologically sound practices in the region. The available documentation on the seasonal resource dependence established over generations of reciprocity by the two distinct communities shows its significance for achieving the ecologically sustainable production systems in the region. The knowledge generated through this review also gives us hope that it is possible to rekindle the weakening symbiotic reciprocity by introducing appropriate policies and processes highlighting the sustainable resource sharing mechanisms between these communities of practice.

References


THEME 5- DROUGHT MANAGEMENT AND CLIMATE CHANGE IN RANGELAND/GRASSLANDS

Topic: Droughts and Degradation – Social Ecological Perspectives on Tipping Points in Dryland Rangelands
Rangeland management in Namibia in the face of looming desertification: Insights from the freehold farmers’ perspective

Brinkmann, K.1,2*; Liehr, S.1,2; Lena Bickel1

1 ISOE – Institute for Social-Ecological Research, Hamburger Allee 45, D-60486 Frankfurt am Main, Germany
2 Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Georg-Voigt-Straße 14, D-60325 Frankfurt am Main, Germany
* Corresponding author email: brinkmann@isoe.de

Key words: local knowledge, risk mitigation strategies, income diversification, Waterberg

Abstract

Namibian rangelands are a prime example of tightly coupled social-ecological systems (SES) in drylands. Although, pastoralists and farmers are aware of unpredictable and insufficient rainfall and have adapted their management during history, the impact of droughts is becoming increasingly severe in the face of looming desertification. Improving our understanding on the capacity to cope with desertification risks is essential to sustain this SES. We, therefore, aimed to explore farmers’ perceptions on desertification and the resulting adaptation measures to desertification. We focussed on freehold farmers (FF) of the Waterberg conservancy. To gain insights on local knowledge, land use changes and farm characteristics in past and present, a mixed method approach was used, comprising, semi-structured interviews, participatory mapping, focus group discussions and remote sensing techniques. The main changes compared to the past were the decrease of cattle numbers, the abandonment of crop cultivation as well as sheep and goat husbandry and the diversification of farm-income through alternative activities. FF had a very complex view on causes and effects of desertification which is mostly in line with the scientific view. The majority of FF already experienced desertification in the past and reported a decrease in grass biomass. FF apply short-term risk coping strategies as immediate response to drought that include the reduction of livestock numbers, use of supplementary fodder or dodge to reserve camps. Recently implemented long-term risk mitigation strategies in response to dwindling fodder resources due to desertification comprise income diversification and investments in restoring rangelands (e.g. bush control, also combined with the production and use of bush feed, holistic management). The latter has the potential to reduce or even halt desertification. However, there is an urgent need to guide and promote such proactive management through appropriate methods of knowledge transfer that bridge the gap between science and practice.

Introduction

Namibian rangelands, which occupy roughly 50 % of the land and are used for livestock farming (MEA 2005), are a prime example of tightly coupled social-ecological systems (SES) in drylands. During the last decades, rangeland desertification with the loss of perennial grasses and increasing bush encroachment (D’Odorico et al., 2013) threatens the fodder resources of livestock and game. The loss of these valuable ecosystem services directly affects farmers’ livelihood and diminishes farm income in the long term. Although, pastoralists and farmers are aware of unpredictable and insufficient rainfall and have adapted their management during history, the impact of droughts is becoming increasingly severe in the face of looming desertification. Improving our understanding of the capacity to cope with desertification risks is essential to sustain this SES. We therefore aim to explore the historical context of desertification, farmers’ perceptions on desertification and the resulting adaptation measures to desertification. Our study region comprises semi-arid rangelands of the Greater Waterberg Landscape, approx. 250 km north of Windhoek. We focussed on commercial land that has been exclusively managed by property-owning freehold farmers (FF) for decades. To gain
insights on local knowledge and practices, land use changes and farm characteristics in the past and present, a mixed method approach was used, comprising semi-structured interviews, focus group discussions and remote sensing techniques in order to capture both social and ecological dynamics and to be able to relate them to each other in space and time.

**Materials and Methods**

Semi-structured interviews with FF (n = 10) were conducted to analyse the historical context, social drivers, and effects of desertification. The interview guideline contained questions centred on farm characteristics, rangeland management and connected problems, characteristics of desertification processes in pastureland and farmers’ strategies to cope with desertification (current and past). Qualitative in-depth interviews were conducted with FF to gain insights into farmers’ perceptions on causes and effects of desertification and depict the causal relations between elements in a fuzzy cognitive map (FCM). We used the FCM approach of Özesmi and Özesmi (2004) and finally merged the resulting FCMs into a single augmented representation. Furthermore, focus group discussions with Namibian rangeland experts were conducted to discuss and assess strategies to combat desertification.

To analyse land use and land cover changes on commercial farms over the past 50 years, historical panchromatic Corona images (KH-4A, Dashora et al., 2007) from August 1972 and a recent Sentinel 2 image from August 2019 were acquired from the United States Geological Survey. An object-based classification approach was applied within ArcGIS 10.6 (ESRI Inc., Redlands, CA, USA) using simplified land cover classes (woodland, shrub dominated savannah, grass dominated savannah, barren land, and water areas). Image segmentation was performed using the mean shift algorithm. Training data for the different land cover categories was identified for each segmented image and subsequently used for supervised classification with the Random Forest method (Breiman 2001) using 100 trees and 50 bootstrap samples. To account for changes in land use, we further digitized the visible agricultural fields and camp areas on the original images for 1972 and 2019 and compared their changes.

**Results and Discussion**

The average farm size of FF was 12,062 ha with a mean cattle number of 626. An overview of the different activities contributing to farm income showed a strong diversification of farmers’ income and a high heterogeneity in the operational orientation of the interviewed farmers in the Waterberg Landscape area (from pure cattle farms to game farms and guest farms with few or no cattle left). Depending on the operational orientation of the farms, different pasture management strategies were applied (stocking density, rotation rules, camp size, resting periods for camps). The majority of FF already experienced desertification in the past and reported a decrease in grass biomass. FF had a very complex view on causes and effects of desertification, which is mostly in line with the scientific view. According to the FF, especially higher stocking densities in the past led to overgrazing, which accompanied with frequent drought events triggered desertification processes. FF particularly highlighted bush encroachment on pastureland and the loss of perennial grass cover as severe desertification effects (Figure 1).

![Figure 1: Fuzzy cognitive map (FCM) of freehold farmers’ perception on causes (white boxes) and effects (grey boxes) of desertification in the Greater Waterberg Landscape of Namibia.](image-url)
Line thickness indicates how often the factor was mentioned by respondents.

Among the most important changes on farms over the past 50 years are the decline of cattle numbers, the abandonment of sheep and goat husbandry, and the diversification of farm income through alternative activities. FF income portfolios have been substantially diversified away from livestock production. Land cover and land use classification results revealed an increase of shrub dominated savannah on rangeland areas from 650 km² in 1972 to 757 km² in 2019 as a result of bush encroachment, whereas woodland decreased by 28 km². The overall trend of shrub cover varied between and within FF with bush encroachment observed on 65 % of camps as well as a shrub decrease due to de-bushing measures on 35 % of the camps. Compared to the past, the number of camps on pastureland increased and nearly doubled from 1972 to 2019 signifying a decrease in area of the pasture management units. Compared to 1972, when crop production was a relatively successful enterprise (Fuller 1993), almost all agricultural fields disappeared until 2019.

FF apply short-term risk coping strategies as immediate response to drought that include the reduction of livestock numbers, dodge to reserve camps or the use of supplementary fodder (Figure 2). The latter includes the use of bush feed, which comprises both, purchased feed pellets and bush feed originated from own production using a wide variety of processing techniques. In total, 73 % of the farmers reported that the grass biomass is declining and that they are increasingly switching to alternative feeding strategies. Recently implemented long-term risk mitigation strategies in response to dwindling fodder resources due to desertification comprise income diversification and investments in restoring rangelands (e.g. bush control, also combined with the production and use of bush feed, holistic management). In contrast to farmers practice, the experts rated governance measures as one of the most important long-term risk mitigation strategy.

**Figure 2:** Short-term risk coping strategies and long-term risk mitigation strategies to desertification in the Greater Waterberg Landscape in Namibia practiced by farmers (n = 10) and rated as important by experts (n = 15) during focus group discussion (% of respondents).

**Conclusions**

Long-term risk mitigation strategies to combat desertification have the potential to reduce or even halt desertification. However, there is an urgent need to explore the constraints of their implementation to guide and promote proactive management through appropriate methods of knowledge transfer that bridge the gap between science and practice. To ensure that farmers can better cope with future challenges, current practices need to be considered and farmers’ and experts’ knowledge should be better integrated. In this context, the capability of FCM to depict FF’ perceptions and knowledge in a structured way contributes to detect knowledge gaps to constructively work through.

**Acknowledgements**

We acknowledge the financial support from the German Federal Ministry of Education and Research (http://www.bmbf.de/en/) via the “NamTip” project (grant 01LC1821E) within the BioTip Program.

**References**


Comaniciu, D. and Meer, P. 2002. Mean shift: a


Strategies for assessing grassland degradation with biogeochemical models

Rolinski, S.; Wirth, S.B.; Müller, C.; Tietjen, B.

1 Potsdam Institute for Climate Impact Research, Potsdam, Germany; 2 Freie Universität Berlin, Theoretical Ecology, Berlin, Germany

Key words: biogeochemical modelling; drought; grass community composition;

Abstract

Marginal grasslands provide the basis for global livestock rearing and rural livelihoods but are subject to permanent mismanagement and climate change degradation. Global biogeochemical models cannot represent degradation tipping points in marginal grasslands because plant growth depends only on bioclimatic conditions and nutrient availability. Due to their central role in sustaining livelihoods, this lack of representation in such models needs to be addressed. We present an idea on processes and interactions to be considered and the implementation of necessary changes. The model for which we exemplarily develop implementation strategies, LPJmL, accounts for grassland dynamics globally in a fully coupled framework, including soil dynamics and the hydrological cycle. Recent developments include the implementation of grassland harvesting schemes, the nitrogen cycle, fire management practices and representation of a variety of grass and legume species. Existing knowledge on annual and perennial grass species’ role in drought resistance will be utilised to advance model development. Different strategies for forming below-ground plant organs (roots and storage) have to be better understood from experimental studies before this can be implemented in models. Here, assumptions on functional relationships can be implemented, and the resulting grass productivity can be analysed compared to field observations.

Additionally, closed swards or tussocks’ formation plays a big role in the vulnerability to degradation by avoiding bare soil patches. This spatial phenomenon is usually neglected in models and can only be included by assumptions or in the form of aggregated effects. Finally, the long-term development of seed banks of key species determines the regrowth capability after major drought periods, so seed bank formation and persistence is another component of necessary model development. Together with current developments of species competition and niche separation, all these components would build a framework that allows scenario assessments on tipping points depending on climatic conditions and management.

Introduction

Marginal grasslands play an important role in sustaining livelihoods in regions where crop cultivation is not feasible because of the prevailing climatic conditions and soils (Blair et al., 2014, O’Mara, 2012). A major share of marginal grasslands is located in arid or semi-arid regions such as steppes in cooler climates or as part of savannahs in warmer climates (Suttie et al., 2005). Under these conditions, a range of ruminant livestock systems exists, which provide nutrition and income to the local population (Mishaud, 2004). However, the productivity and the provision of livelihoods from marginal grasslands are threatened by degradation from mismanagement, overgrazing and climate change (Kirtman et al., 2013, Collins et al., 2013, Kemp et al., 2013). Extensive mismanagement and overgrazing can have almost irreversible effects when tipping points are reached (Fernández-Giménez et al., 2017, Scheffer et al., 2001), while climate change may generally increase the stress on the vegetation (Wu et al., 2011, Beier et al., 2012), pushing currently non-degraded and well-managed systems towards degradation. Changes in frequency, duration and intensity of droughts will require new or adjusted management practices to maintain livestock-dependent livelihoods. Global biogeochemical models (dynamic global vegetation models, DGVM) are so far not able to represent such tipping points that refer to drastic and often non-reversible shifts between different states of ecosystems (Reyer et al., 2015).
In DGVMs, plant growth is dependent on bioclimatic conditions and nutrient availability. Still, several important mechanisms are missing: First, the co-existence of different species with different ecological strategies to deal with drought, including trait plasticity, tolerance and avoidance. Second, feedback between damage to vegetation cover from grazing or trampling to soil erosion (Knoll and Hopkins 1959). Third, seed banks’ formation allows marginal areas to re-establish vegetation after long periods of unfavourable climatic conditions. We refer to the LPJmL dynamic global vegetation model (Schaphoff et al., 2018) as an example to lay out a path towards the integration of the mechanisms described above. The LPJmL model already accounts for global grassland dynamics in a consistent framework with coupled carbon and nitrogen dynamics in soils and plants, as well as hydrological processes (von Bloh et al., 2018). Here, we develop ideas about the processes and interactions that should be considered in such models as LPJmL to better represent important grassland dynamics and tipping points and discuss the implications of the necessary implementations. With this, we aim to provide a conceptual framework and a more tangible blueprint for other grassland modelling groups.

**Materials and Methods**

LPJmL is a DGVM that explicitly represents managed grasslands. It simulates carbon, nitrogen, water cycles within the soil plant atmosphere continuum. The vegetation consists of plant functional types (PFT) that one average individual per PFT represents in the model. Their growth is simulated daily, including the following processes: (a) reproduction of present PFTs and establishment of new PFTs, (b) turnover of plant material and litter and soil organic matter, (c) change of biomass as a result of gross primary production (GPP) and respiration, with (d) limitations according to environmental conditions and competition for resources. Direct biotic interactions are not implemented. We will briefly describe those processes for which we discuss the need for improvement to represent degradation tipping points and refer to Schaphoff et al. (2018) and von Bloh et al. (2018) for a detailed model description.

For each PFT, LPJmL simulates one average individual characterised by a given set of traits and consists of leaf and root biomass, i.e. ignoring differences between individuals of the same species. The development of the average individual is scaled up to the grid cell area, which covers an area of 0.5 by 0.5 degrees in the standard application but can be applied at any spatial scale. Photosynthesis is described by a simplified Farquhar model (Haxeltine & Prentice 1996) together with a big leaf approach. It derives numerically the optimum photosynthetic activity as a trade-off between light and RuBisCo availability. A key determinant of the calculated photosynthesis is the vegetation cover of each PFT, which is a function of the PFT’s specific leaf area index (LAI) and light extinction coefficient. Due to the non-linearity of this function and because total foliage projected cover (FPC) must not exceed 100%, the realised FPC of each PFT is weighted by all PFTs present in the plot. Limitations due to water and nitrogen stress are accounted for by comparing resource demand and supply. Plant available soil water for each PFT depends on its maximum water transport capacity, vertical root distribution, and FPC. If the demand cannot be fulfilled, a reduced stomatal conductance is calculated from the water supply to adjust the PFT specific photosynthesis. The establishment of new PFTs and expansion of already established PFTs into non-vegetated areas is computed daily. Each PFT can establish independent of the current occurrence of the PFT if bioclimatic limits of the PFT and the unvegetated regions allow for establishment.

**Results and Discussion**

We identified three areas in which additional model development is needed to represent tipping points of degradation—first, the representation of the plants’ physiology, especially below-ground plant organs. Second, the patchiness of the vegetation and the differentiation between closed swards and tussocks. Third, the seed formation and the maintenance of seed banks.

**Plant physiology**

To simulate adequate community responses to changing environmental conditions management, a more detailed representation of the plant itself is necessary (Herrero et al., 2000). Considering different plant architecture within available models, we focus on the widespread differentiation of plants in DGVMs as several carbon and nitrogen pools. Still, we are aware of more sophisticated allometric descriptions, such as in individual-based models (e.g. GRASSMIND, Taubert et al., 2012). In addition to the plant compartments, leaves and roots, models should account for above- and below-ground storage organs, which allow for survival under unfavourable conditions and improve the recovery of the plant community after a drought. Leaves should further be distinguished.
into photosynthetically active and senescent leaves that are still attached to the plant, as this will improve the representation of the litter cover. The coverage of the soil by dead or live biological material alters the properties of the soil surface, which influences its vulnerability to degradation. Another aspect is the consideration of root traits and their role in acquiring resources. So far, roots are underrepresented in DGVMs because of scarce knowledge. However, initiatives such as GRooT (Guerrero-Ramirez et al., 2021) recently improved data availability. These data may connect water and nutrient uptake to functional traits allowing to simulate additional trade-offs within plant strategies. Especially in arid and semi-arid regions, growth strategies for leaves and roots are strongly linked to resilience and degradation of grasslands (Puigdefábregas 1998). Therefore, an improved representation of roots is essential to understand the causes and consequences of degradation better and to develop management strategies that avoid grassland degradation.

Figure 1: Schematic representation of grass plants by leaves and roots only (old, left) and additional plant compartments of brown leaves and a storage (new, right).

Patchiness

The degree of patchiness of a grassland, ranging from a closed sward without bare soil towards patchy vegetation cover dominated by a number of tussocks, is important for its resistance against soil degradation (Puigdefábregas & Sanchez 1996, Lal 2012). Here, the performance of large-scale models such as DGVMs is strongly limited because the coarse spatial resolution precludes an explicit simulation of the spatial configuration of covered and bare patches. To overcome this, small scale individual-based models could be used to systematically assess the vulnerability and reaction of the vegetation regarding different levels and patterns of patchiness (or amounts of bare soil) to derive scaling relationships for simulations of DGVMs at larger scales. Even though approaches are using statistical models to upscale patchiness effects (Wang et al., 2018), a dynamic understanding would enhance the ability to represent the process at larger scales.

Seed banks

While grass plants mainly reproduce vegetatively, their survival in marginal environments may still depend on generative reproduction via seeds. While large investments into seed formation are unnecessary in productive environments, in marginal environments prone to unfavourable conditions, a well-maintained seed bank is necessary to re-establish after periods of stress. However, the current implementation does not distinguish these strategies and assumes constant seeds for re-establishment. Overcoming this will allow for better assessments of grassland resilience and long-term dynamics.

Conclusions

With the example of LPJmL, we showed that current generation DGVMs need substantial development to simulate degradation of marginal grasslands. We identify current limitations in LPJmL and how these could be overcome. As large areas are marginal grasslands globally, large-scale modelling tools, such as DGVMs, are necessary to assess their dynamics and vulnerability to climate change and changes in management, such as livestock densities and grazing frequencies. A better understanding of degradation tipping points is necessary to assess climate change impacts on grassland ecosystems as well as on herders and transhumance livelihoods.

Acknowledgements

SR acknowledges financial support from the project CLIMASTEPPE (01DJ8012), funded by the German Federal Ministry of Education and Research (BMBF). In addition, SBW acknowledges financial support from the Evangelisches Studienwerk Villigst foundation under the research program: “Third Ways of Feeding The World”
References


Von Bloh, W., Schaphoff, S., Müller, C., Rolinski, S., Waha, K., and Zaehle, S., 2018. Implementing the nitrogen cycle into the dynamic global vegetation, hydrology, and crop growth model LPJmL (version 5.0). Geosci. Model Dev., 11:2789-2812.


Stakeholder attitudes towards wildlife-based land use in Namibia’s Kunene Region

Luetkemeier, R.*1,2; Kraus, R.1; Mbidzo, M.3; Hauptfleisch, M.3; Liehr, L.1,2

1ISOE – Institute for Social-Ecological Research, Frankfurt/Main, Germany
2Senckenberg Biodiversity and Climate Research Center (SBiK-F), Frankfurt/Main, Germany
3Namibia University of Science and Technology (NUST), Windhoek, Namibia

Key words: Rangeland system, livestock farming, wildlife conservation, tipping points, stakeholder analysis

Abstract

African rangeland systems are characterized by competing resource use for livestock farming and wildlife conservation. In Namibia’s rangeland savannahs, cattle farming for commercial and subsistence purposes is common, shaping the land use system of the country’s north. Local cattle stocking rates increased over the past decades and triggered ecosystem degradation that became visible in the last drought-stricken years. Cattle was lost, meat prices dropped and livelihoods were threatened. It is assumed that current land use activities are pushing the rangeland ecosystem towards ecological tipping points. Alternative approaches to use the scarce resources of rangelands in a more sustainable way may be centred on wildlife-based land use strategies. Against this background, we investigate the attitudes of stakeholders towards wildlife in order to carve out current barriers for upscaling wildlife-based land use strategies. We conducted stakeholder mapping based on the results of a larger qualitative survey, which included a workshop, individual interviews and a participatory observation. Our results indicate that the reasons for stakeholders being hesitant towards wildlife-based strategies can be clustered around (i) cultural and traditional practices, (ii) unfavourable market conditions and (iii) negative connotations of certain wildlife utilization practices. The study results contribute to the identification of entry points for policies that seek to support wildlife-based strategies.

Introduction

Rangeland systems are a typical feature of African landscapes and important as natural habitats and for agricultural utilization (Du Toit et al., 2012). However, competing uses of rangelands for nature conservation and in particular livestock farming result in resource competition and thus declining wildlife numbers (Holechek and Valdez 2018). The dominance of livestock farming in certain parts of Namibia, for instance, led to overgrazing and land degradation (Menestrey Schwieger and Mbidzo 2020) which is particularly critical during drought periods as in the past years (Blamey et al., 2018). These degradation processes may potentially lead to ecological tipping points that are regarded as critical threshold at which the rangeland system switches to a new stable state with new dominant but less beneficial plant communities (Bestelmeyer et al., 2017). It is an open question, if key features of the rangeland system that support wildlife and agricultural utilization are maintained after this transition.

One potential strategy to prevent rangeland degradation and hence the emergence of tipping points is seen in wildlife-based management strategies. The diversity of local endemic herbivore species is considered to be a key element for sustainable rangeland ecosystems as herbivores have varying feeding preferences and can hence make use of more vegetation types than conventional livestock species (Smet and Ward 2005). Wildlife could thus be considered a climate-change proof land use strategy for the future. In this regard, wildlife-based land uses are supported by the Namibian government since decades. The country is one of the few worldwide, in which people are legally eligible to utilize wildlife resources. For instance, farmers can generate income from wildlife species by offering photo-tourism or hunting experiences as well as selling wildlife meat products (GRN, 1975, 1996). However, these benefits also come with disadvantages as human-wildlife interactions can cause conflicts (MET/NACSO, 2018a). This
makes it difficult for certain stakeholders to tolerate wildlife as conventional livelihoods may not be compatible with their occurrence.

In this study, we investigate the attitudes of stakeholders towards wildlife in part of Namibia’s Kunene Region. We consider this as a relevant first step to identify and understand current barriers for further expansion of wildlife-based management strategies. We make use of qualitative social science methods as presented in the following section, to map stakeholder attitudes and thus shed light on current barriers for people to adopt forms of wildlife-based land uses.

**Materials and Methods**

For our study, we chose an area located in the Kunene Region in Namibia as both conventional farming practices and wildlife-based management strategies come together. The rangeland south-west of Etosha National Park (ENP) is characterized by a tree and shrub savannah biome with an average rainfall of about 100 to 350 mm per year (Mendelsohn et al., 2003). It is characterized by frequent droughts as being observed within the last years (Blamey et al., 2018), and uncertainties with regard to climate-change induced precipitation patterns (Niang et al., 2014). These circumstances are already pressuring the agricultural sector and causing uncertainties for long-term land management options (Reid et al., 2008; Wilhite et al., 2014). Within the area of interest, natural resources are used in different ways: Livestock farming with cattle, sheep and goats is the conventional practice and applied by most of the land users of communal and commercial farmers (Kraus 2020). Besides, wildlife-based management options have gained in popularity over the last decades as they were supported by governmental policies (MET 2007). In the study area, those strategies focus on tourism that offer photo safaris and hunting experiences (Kraus 2020). In this regard, income is generated through tourism as well as meat production. Furthermore, different land tenure systems prevail: While freehold farms are privately owned, communal conservancies are established on state land (MET/NACSO 2018b).

We made use of the qualitative results of a larger survey which focused on conflicts that emerge from human-wildlife interactions and which included a project workshop, individual interviews and a participatory observation (see Luetkemeier et al., in prep. for details on the methodology). We screened the qualitative data to obtain insights into stakeholder attitudes towards wildlife and to carve out barriers that hinder actors to follow wildlife-based strategies. In order to map stakeholder attitudes, we compiled a list with more than 50 potential stakeholders that have an influence on how wildlife is utilized in Namibia. This list includes both directly involved individuals such as communal and freehold land users as well as indirectly involved actors such as businesses (e.g., supermarkets) and international tourists. The stakeholder attitudes were mapped according to the following three questions:

“Would the stakeholder be in favour of an expansion or intensification of...

- ...wildlife conservation in general,
- ...consumptive use of wildlife (encompassing all legal activities that result in killing wildlife),
- ...or conventional livestock farming?”

Each stakeholder was matched with respect to the three questions on a scale from -2 (not in favour) to 2 (in favour). Four researchers of the project team conducted this mapping task individually, having the qualitative material and overall experiences in human-wildlife interactions in Namibia as background information. Their individual mapping results were finally averaged and again grouped into seven stakeholder groups to be depicted on a 3D-chart for better illustration.

**Results**

In order to provide a more tangible picture on the stakeholder attitudes, the actors were categorized into seven distinct groups. Figure 1 provides a visual representation of how we evaluated the qualitative interview material and mapped the attitudes of stakeholders towards (i) the expansion of conservation measures, (ii) consumptive use of wildlife and (iii) conventional livestock farming.

Starting in the upper-left corner of Figure 1, the groups ‘Agriculture’ and ‘Trade & Commerce’ rank high in favour of an expansion of conventional livestock farming and at the same time remain rather passive when it comes to ideas to further expand current wildlife conservation activities. This does not mean that these actors are against conservation in general; it is rather assumed based on the available empirical information that they are content not to expand activities in this direction due to their own business objectives. With regard to consumptive use activities, both groups are rather neutral with large in-group heterogeneity. While some individual stakeholders of the group ‘Agriculture’, for instance, are considered to value the option for predator control (positive aspect), others are regarded to consider it an undesired
side-effect as it promotes a shift to wildlife-based land uses in a livestock-dominated area (negative aspect).

Moving on to the right-hand side of Figure 1, the two groups of ‘Media’ and ‘Government’ score higher on the conservation axis as compared to the aforementioned groups. This means, the actors of these two groups are considered to prefer an expansion of wildlife conservation measures. While we see the governmental bodies to also favour conventional livestock farming (higher on y-axis), specifically due to its role for the Namibian economy, the ‘Media’ actors are not regarded to share this positive attitude to such an extent. Here, it is important to emphasize the exclusion of social media providers, as these rather act as platforms and not intentionally as opinion leaders. When it comes to consumptive use, the ‘Media’ remains passive (e.g. due to moral implications), while actors of the ‘Government’ group partly support activities in this direction (e.g. due to conservation benefits and economic returns).

![Figure 1: Stakeholder attitudes towards an expansion of conventional livestock farming (y-axis), conservation (x-axis) and consumptive use (z-axis), aggregated into major stakeholder groups.](image)

The two groups ‘Conservation’ and ‘Tourism’ score high on the conservation axis and low on the livestock-farming axis. Both groups are considered to support wildlife-based management practices, while the essential difference between them can be found in their appreciation of consumptive use activities. The stakeholders within the group ‘Science’ are considered as supporters of conservation measures, while they are less in favour of conventional livestock farming. This group also sees potential in consumptive use activities, especially for conservation purposes.

**Discussion**

Our stakeholder mapping revealed clear differences in attitudes towards wildlife. For wildlife-based strategies to be accepted by Namibian stakeholders as a climate-proof strategy to prevent critical ecological tipping points in savannah rangelands, certain barriers especially in the sectors of agriculture, trade and commerce have to be addressed. Based on our stakeholder mapping procedure and the qualitative interview results, we would like to carve out three major barriers for wildlife-based strategies that can be found in (i) cultural and traditional practices, (ii) unfavourable market conditions and (iii) negative connotations of certain wildlife utilization practices.

First, actors from the agricultural sector remain hesitant in adopting wildlife-based management
Joint XXIV International Grassland and XI International Rangeland Kenya 2021 Virtual Congress Oral Papers Proceedings

strategies partly for traditional reasons. Some commercial and communal farmers hold on the conviction of livestock farming as an obligation to maintain tradition and reproduce cultural knowledge. They consider this practice as an identity-forming activity. While for freehold farmers the core reference point seems to be the obligation to continue family business, communal farmers consider large herds of livestock as a form of wealth and social status.

Second, actors from the sectors of ‘Agriculture’ and ‘Trade and Commerce’ see financial obstacles in market related issues. The financial burden to shift agricultural practices away from livestock farming is considered excessive in combination with limited revenue prospects due to an increasing competition for tourists among wildlife farmers. In addition, consumer behaviour is considered a barrier as demand for wildlife products remains low and beef demand is considered constant, despite recent price variations. In this context, the European Union is a key reference point as an important export market where consumer preferences still prefer beef over wildlife products.

Third, the respondents indicated that an overall negative perception of certain consumptive wildlife use practices is prevalent in the public discourse. Hunting activities are seen critical by a range of actors such as non-governmental organizations in the environmental sector and international tourists who primarily come for photo tourism activities.

Acknowledgements
This research was conducted under the umbrella of the ORYCS project (www.orycs.org) which is a German-Namibian research project, funded by the German Federal Ministry for Education and Research (BMBF) with the funding number 01LL1804C. The empirical survey was conducted with additional funds from the University of Vienna and with the permission of the Namibian National Commission on Research Science and Technology (NCRST), certificate number RCIV00032018 and the authorization number 20190602.

References


Kraus, R. 2020. Impact assessment of fences and land use on landscape permeability for African elephants (Loxodonta africana) south of Etosha National Park, Kunene Region, Namibia, University of Vienna. Vienna.


MET/NACSO 2018b. The state of community conservation in Namibia.


Reid, H., Sahlén, L., Stage, J. et al., 2008. Climate change impacts on Namibia’s natural resources and economy. Climate Policy, 8(5): 452-466.


Towards early warning signals for desertification

Klingenfuss, Sara¹; Heshmati, Sara²; Ruppert, Jan C.²; Tielbörger, Katja ²

¹Institute of Evolution and Ecology, University of Tübingen, Auf der Morgenstelle 5, 72076 Tübingen, Germany and Department of Geobotany, University of Freiburg, Schauenzestr.1 79104 Freiburg, Germany
²Institute of Evolution and Ecology, University of Tübingen, Auf der Morgenstelle 5, 72076 Tübingen, Germany

Key words: Desertification; tipping point; early warning signal

Abstract

Dryland ecosystems cover a large share of the world’s terrestrial surface. Deficiency and spatio-temporal variability of precipitation and low vegetation growth rates make dry rangelands prone to degradation, especially under changing climate and intensified land use. Degradation often occurs gradually, but sometimes, a sudden and surprising shift from a healthy to degraded rangeland can be observed, where perennial grasses are lost and bare soil is exposed. If such changes are sudden and irreversible, they have coined a tipping point. Due to their abrupt appearance, it is a great challenge to discover early warning signals that precede the regime shifts. Theory predicts that variance and autocorrelation in state conditions could be used as early warning signals. However, these theoretical assumptions have rarely been tested in real ecosystems. Here, we use a data-based approach to fill this research gap using desertification processes in semi-arid rangeland as a case study. In order to test the applicability of theoretical early warning signals for tipping points, we looked at a dataset from Widou, Senegal, that includes annual observations of rainfall, grazing intensity and primary production from 1981 to 2007. In addition, we analysed productivity-based metrics, such as rain use efficiency, to detect patterns that may precede a shift between alternate stable states. Strong signals of a regime shift were detected that were expressed in a sudden alteration of species composition and a general decline of productivity after a drought. However, we did not find any changes in the theoretically proposed parameters that may reflect early warning signals for a critical transition, i.e. the regime shift was essentially unpredictable. We suggest that while the theory around tipping points and early recognition thereof may be robust, the applicability of theoretical concepts to the real world may be challenging.

Introduction

Under changing climatic conditions and intensified land use, dry grasslands are prone to degradation because of the deficiency of precipitation and spatio-temporal variability. The transition from a healthy to a degraded state has been observed as a sudden and surprising shift, where feed grasses are lost, and bare soil conditions dominate. This transition is often discussed in the context of regime shifts or tipping points, where a system shifts from one alternative stable state to another (Rietkerk et al., 2004). These transitions are often considered irreversible without major renaturation efforts (Angeles et al., 2013). Being able to forecast these transitions before they occur is thus of utmost importance and a crucial prerequisite for the implementation of targeted management strategies. Whether or not a regime shift is near might be detected with generic indicators that together are known as the phenomenon of critical slowing down (CSD) (van Nes and Scheffer, 2007). CSD works across a variety of complex systems and comprises the patterns that form when return rates to equilibrium slow down (Carpenter and Brock, 2006). Slowed down recovery is expressed in a greater variance and increased temporal correlation before a regime shift. These patterns are proposed to arise before many different transitions in ecosystems, including desertification (Scheffer et al., 2009). Bestelmeyer et al., 2013, tested whether measurements based on patchiness and vegetation cover might serve as early warning indicators and found that grass cover was the main determinant of variation in recovery, therewith signalling...
an upcoming transition. This supports the idea that simple productivity-based metrics might already contain sufficient information to analyse weather patterns related to the early recognition of critical transitions that arise in the context of dryland degradation. Productivity-based metrics are known to retrospectively capture structural changes in vegetation related to desertification (Verón and Paruelo, 2010). Rain use efficiency (RUE) represents one of these metrics. It relates net primary production to rainfall and informs about the system’s ability to use rainfall. Hence, it may indicate the degradation of the system (Kaptué et al., 2015).

This study investigates the influence of drought and grazing pressure on threshold dynamics in drylands and the potential of simple productivity-based metrics as early warning indicators. We hypothesise that annual RUE is sensitive to changes around tipping points and shows patterns of increased variance and temporal correlation, with more pronounced patterns for more heavily grazed systems.

**Methods and Study Site**

We analyse a long-term set of field-derived productivity data that was collected and first published by Miehe et al., in 2010. The ecosystem is characterized as a thorn bush-savanna with the herbaceous layer mainly comprised of annual grasses and is primarily used as rangeland. Aboveground biomass of the herbaceous layer was harvested annually at the time of maximum vegetation development at the end of the growing season to measure annual net primary productivity (ANPP). Peak standing crop was measured in four different grazing intensity regimes i.e., “no grazing/exclosure”, “low grazing”, “high grazing” and “free grazing”. Intensities were created by excluding animals for the exclosure treatment, or by controlling livestock numbers for the low and high grazing. The free grazing treatment was considered the highest grazing intensity; in this case livestock was managed by the local community. As a measure for drought, we used the effective rainfall of the hydrological year (calculated by Miehe et al., 2010). Miehe et al., report that degradation events following the drought became visibly apparent in the grazed study sites in 1996. After this year, biomass production declined severely in the grazed plots.

To find symptoms of critical slowing down (CSD), we assessed patterns before and after this potential regime shift in 1996. We compared these two phases in our time series to better understand the dynamics in CSD-related metrics around the potential shift. The variance over time and temporal relationships within the time series were analysed to display symptoms of slowed down recovery. Rain use efficiency (RUE) was calculated by dividing ANPP by effective annual rainfall. Patterns in the variance of RUE were identified by computing the variance around mean RUE within sliding windows of 4 years. We used forecasting to explore changes in temporal relationships before the degradation event. Therefore, we based our analysis on a simple naïve forecasting model, which takes into account the start and the end of the time series and the values from previous years. Predicted values can then be compared to the observed values, and deviations can be detected (Equation 1). Deviations are reflected in the forecast error of RUE over time (\( \varepsilon_t \)), which was calculated using a random walk with drift model (Equation 2), which predicts every value from the last observation (\( \tilde{y}_t \)) and the average change across all observations (\( \bar{y} \)), where \( T \) is the total length of the time-series, allowing the forecasts to have an upward or downward trend, which would be desirable in this case (Hyndman and Athanasopoulos, 2014).

\[
\varepsilon_t = y_t - \tilde{y}_t \tag{1}
\]

\[
\tilde{y}_t = \tilde{y}_{t-1} + \frac{y_t - \bar{y}}{T-1} \tag{2}
\]

Since we were interested in the inaccuracy of forecasts, independent of the direction of inaccuracy, we used absolute values in the following analyses. To test whether the forecast errors or the variance differs between grazing intensity and the phase in our time-series (before and after the degradation) and whether there is a combined effect of these factors, we used a Linear Mixed Model (LMM) with forecast error/variance in RUE as the response variable, grazing intensity and phase as fixed factors and site as a random factor. Specific effects of phase within grazing intensity were tested using post hoc pre-planned contrasts in combination with a Dunn-Sidak correction. Data were tested for normal distribution by a visual assessment of the histograms of the collected data (Zuur et al., 2010).

In order to fulfil assumptions of LMMs, the data were log-transformed. The Levene-Test was used for testing homogeneity of variances, and results fulfilled the assumption of homoscedasticity. Plots were created using the loess-smoothing method that is based on a local regression approach which fits multiple regression to small subsets of the data.

To understand the dynamics in CSD-related metrics around the potential shift. The variance over time and temporal relationships within the time series were analysed to display symptoms of slowed down recovery. Rain use efficiency (RUE) was calculated by dividing ANPP by effective annual rainfall. Patterns in the variance of RUE were identified by computing the variance around mean RUE within sliding windows of 4 years. We used forecasting to explore changes in temporal relationships before the degradation event. Therefore, we based our analysis on a simple naïve forecasting model, which takes into account the start and the end of the time series and the values from previous years. Predicted values can then be compared to the observed values, and deviations can be detected (Equation 1). Deviations are reflected in the forecast error of RUE over time (\( \varepsilon_t \)), which was calculated using a random walk with drift model (Equation 2), which predicts every value from the last observation (\( \tilde{y}_t \)) and the average change across all observations (\( \bar{y} \)), where \( T \) is the total length of the time-series, allowing the forecasts to have an upward or downward trend, which would be desirable in this case (Hyndman and Athanasopoulos, 2014).
Results

The absolute forecast throughout the study period showed no explicit increase before the expected regime shift. However, forecast errors are overall higher in the time before the supposed regime shift than after it for the grazed treatments, but not the ungrazed sites (Fig. 1). There was an overall decrease in the forecast error after degradation in phase 2, and effects were significant for the low and high grazed sites ($t=3.35; p=0.0034$ and $t=3.074; p<0.0088$ respectively). Sites subjected to the free grazing treatment likewise had a strong trend towards increasing predictability after the reported degradation; however, this was not detectable through statistical analysis ($t=1.060; p=0.7450$). Ungrazed sites showed constant forecast errors across both phases ($t=-0.239; p=0.9987$) (Fig. 2).

The variance was generally higher before the supposed regime shift and decreased thereafter. However, the increase might not be read as a classical increase in the context of CSD because we can see a slight declining pattern before 1986. The decline in variance after 1995 is stronger and faster for grazed sites than exclosure sites (Figure 3).

Testing the mean variance in RUE against effects of grazing intensity and phase (before or after the reported degradation), showed that grazing affects the mean variance in RUE for all grazed sites ($t=7.334; p<0.001$ for low grazing, $t=7.337; p<0.001$ for high grazing, $t=6.409; p<0.001$ for free grazing), with no change in the variance in the ungrazed sites ($t=0.302; p=0.9968$) (Fig. 4).

In general, there is a strong influence of grazing on CSD-related variables, in particular in combination with the phase. No grazing constantly leads to equal values of these variables across the two phases.

---

**Figure 1:** Loess-smoothed absolute forecast errors over time for 4 different grazing intensities. There is a strong forecast accuracy for grazed plots after 1995.

**Figure 2:** Result of the LLM and pre-planned contrast analysis for differences in forecast errors between phase (left bars are pre-1966 and right bars are post-1966), within grazing. Figure shows the mean absolute forecast error per treatment with doubled standard error for the mean. Significant differences are highlighted with asterisks.

**Figure 3:** Loess-smoothed variance in RUE over time for 4 different grazing intensities. There is a strong decrease in variance after 1995, which is drastic in grazed sites. Dynamics of variance in RUE over time in ungrazed sites are less extreme.

**Figure 4:** Result of the LLM and pre-planned contrast analysis for differences in variances between phase (left bars are pre-1966 and right bars are post-1966), within grazing. Figure shows the variance in RUE per treatment with doubled standard error for the mean. Significant differences are highlighted with asterisks.
of the time series, whereas the values in the low and high grazing treatment differ significantly between phases, resulting in higher variance and less predictability before the reported degradation and expected critical transition. The free grazing treatment has likewise a strong trend to display this pattern.

Discussion [Conclusions/Implications]

Our results suggest that the ecosystem we studied is subject to threshold responses and that the strength of disturbances inducing such might be milder than we thought. Signs for a supposed state shift were equally present irrespective of grazing intensity, which has serious consequences for concepts in rangeland management. We found a clear discrepancy between predictability of RUE between grazed and ungrazed sites, with better predictability in the grazed sites after degradation.

This might imply a critical transition occurred, where the system went into an alternative stable state after 1995, resulting in more accurate forecasting ability. Investigating critical slowing down via increased variance yielded similar results. Results show an increase in variance before 1995, followed by a strong decrease in the variance in RUE after the reported degradation, reflecting a higher likelihood for a transition into a new stable state.

Whether or not the apparent fluctuations in variance and predictability around a degradation event fit into the context of CSD is, however, unclear. The extent of the time series used to predict regime shifts is critical because natural fluctuations need to be separated from the threshold response. In a system where the typical generation time of the response organisms is more than one year, even several decades might not be enough. Like in other studies about regime shifts (climatic, economic, etc.), it might be necessary to observe > 100-time steps in order to make sound conclusions (Andersen et al., 2009).

Although we detected rangeland degradation using the available metrics, our analyses showed no clear pattern indicating a critical transition before it happened. Against the expectations that grazing intensity would impact the systems’ likelihood to desertify, there was no difference between low, high and free grazing in the dynamics during/ before degradation, noting that herding control was abandoned in dry seasons after 1992. The data suggests that a combination of disturbances, i.e. repeated drought events as well as grazing by livestock, can drive drylands towards a tipping point. However, detecting the proximity to transition remains beyond recognition. One way to overcome the problem time-series of insufficient extent may be the application of remote sensing (Nijp et al., 2018). These methods may open up the possibility to monitor drylands over large areas and periods, which may enable us to predict non-linear responses to environmental change in the future.

Acknowledgements

We thank Sabine Miehe for the access to the data we used to perform this study.

References

Andersen, T., Carstensen J., Hernández-García, E. Duarte, C.M. 2009. Ecological thresholds and regime shifts: approaches to identification


THEME 6 – PASTORALISM, SOCIAL AND POLICY ISSUES

Topic: International Year of Rangelands and Pastoralists, Part 1:
Panel 1 and 2
International Year of Rangelands and Pastoralists (IYRP) History, Process, Priority Themes and Way Forward

James T. O’Rourke¹; Maryam Niamir-Fuller²; Barbara Hutchinson³

¹Rancher, Chadron, NE USA
²Retired Director of GEF at UNEP, Virginia, USA
³Rangelands Partnership, University of Arizona, USA

Key words: international; rangelands; pastoralists; monthly themes

Abstract
The road towards the declaration of an IYRP by the United Nations has been long and rocky, perhaps mirroring the relative lack of understanding by some governments of the importance of rangelands and pastoralists for a sustainable world, compared to the focus on other sectors such as forest or cropland sustainability. The idea was first discussed at the International Rangeland (IRC) and Grassland (IGC) Congress held in Hohhot, China in 2008. The creation of an International Support Group (ISG) in 2015 helped to provide a stronger rational and the integration of social dimensions. This has led to a growing partnership of national, regional, and international organizations. Numerous events were conducted at international meetings between 2015 and 2021 to solicit support for an IYRP. In 2018, UN Environment published a Gap Analysis of knowledge about rangelands and pastoralism that helped to further highlight the significant neglect of these issues in both academic and development circles. Under the leadership of the Government of Mongolia, the proposal for designation of an IYRP was officially presented in 2019 to the Committee on Agricultural Secretariat of FAO. This historical background provides instructive lessons on how global perceptions can change through strong partnerships. In anticipation of obtaining this designation a comprehensive list of monthly themes has been developed by the ISG to guide countries on outreach and educational activates to take place prior to and during the IYRP. This guidance provides a vision of multi-disciplinary and multi-stakeholder approaches towards integrating the social, economic, environmental and political aspects of sustainability in rangelands and pastoralism. At this Congress resolutions will be submitted to the IRC and IGC for delegate support of this overall effort, including recommendations for Continuing Committee members of both the IRC and IGC along with the ISG to assist individual countries in developing IYRP-related programs.

Historical Context
The first discussions for an International Year of Rangelands were held informally at the Eighth International Rangeland Congress (IRC) in 2008 in Hohhot, Inner Mongolia, China and more formally at the Food and Agricultural Organization (FAO) of the UN although progress on next steps were not successful at that time. Then, at the Ninth IRC held in Rosario, Argentina in 2011 two related Resolutions were passed: a) calling for the UN General Assembly to launch an International Year of Rangelands, and b) requesting support for the concept of a Global Rangeland Assessment (IRC 2011). In 2015 the current effort to gain an International Year of Rangelands began in earnest and became the worldwide initiative it is today. Drawing on the successful example of the 2015 International Year of Soils, members of the Rangelands Partnership (RP) and the leadership of the Society for Range Management (SRM) began exploring how such an International Year could be achieved and making contacts with colleagues around the world. Meetings held at the SRM annual meeting in 2016 resulted in expanding the visibility and number of organizations involved in the effort. At the same time, members of the IUCN and UNEP were cultivating a small group of like-minded people to begin working on a global overview of the “state of the world’s rangelands”. This “small group” quickly expanded and several critical discussions and actions took place as a result.
First, members of the group with strong pastoralist ties discovered there was also a movement for pursuing an International Year of Pastoralists. While there were differing opinions among the groups about the most important intersections of land and people issues, in the end, there was agreement that significant commonalities existed. After some discussion, the groups determined the two efforts would be stronger together. Thus, the International Year of Rangelands and Pastoralists (IYRP) initiative was born!

In 2016, in order to gain intellectual and financial support for both a global IYRP campaign and a global status report on rangelands, attention turned to the United National Environment Assembly (UNEA-2) where countries were debating how to implement the Sustainable Development Goals (SDG). Several countries including Mongolia, Kenya, Ethiopia, and Sudan worked on a last-minute Resolution that was ultimately approved in Nairobi, Kenya on May 26, 2016. Titled: “Combating desertification, land degradation, and drought and promoting pastoralism and rangelands”, the resolution gained high level support from more than 100 countries (UNEA-2 2016). While it did not include language about an IYRP, the resolution did call for:

- raising “global awareness of sustainable pastoralism and rangelands”
- strengthening “the science-policy interface on sustainable pastoralism and rangelands”
- conducting a worldwide gap analysis “to better understand the implications for sustainable livelihoods”

To begin implementing the UNEA-2 resolution, a meeting was later held at the International Rangelands Congress on July 19, 2016 in Saskatoon, Canada. More than 50 representatives from around the world discussed and committed to an action plan of next steps in the IYRP process, including:

- raising awareness at grassroots levels in both developed and developing countries
- continuing to work closely with countries willing to take forward a formal request to the United Nations General Assembly for an IYRP
- promoting an IYRP at future UN-related events as well as at other related conferences and meetings throughout the world.

By early 2017, a more formal “steering committee” for an IYRP had been organized including this paper’s authors as co-chairs as well as a secretariat that established a website for the effort: [https://globalrangelands.org/international-year-rangelands-and-pastoralists-initiative](https://globalrangelands.org/international-year-rangelands-and-pastoralists-initiative). The website now is maintained as the IYRP initiative’s archive for resolutions and documents, PR materials, and meeting minutes among other related resources.

United Nations Process for Gaining Approval for an International Year & Progress Made

Between the years 2016 to 2018, the IYRP Steering Committee promoted the IYRP in multiple fora, including national and regional meetings of pastoralists. For example, in December 2016, a special side event at the Conference of Parties of the Convention on Biological Diversity in Cancun, Mexico acknowledged the importance of sustainable pastoralism and healthy rangelands for biodiversity conservation, and a formal Statement was signed by many pastoral representatives and NGOs calling for the designation of the IYRP. Other supporting statements and declarations quickly followed. At least 27 Resolutions have been passed at various international conferences and meetings over the past 15 years and most recently by gatherings of pastoralists such as by the Coalition of European Lobbies for Eastern African Pastoralism (CELEP), the Pastoralist Knowledge Hub (PKH/FAO), IUCN, and the Yolda Initiative (Turkey); each of these organizations have played critical roles in the success achieved to date.

During this period, GRID-Arendal, funded through UNEP, compiled a Gap Analysis as called for by UNEA-2 (Johnsen et al., 2018), it indicates a lack of understanding of the critical issues faced by pastoralism and rangelands amidst the fast pace of change in today’s world. It recommends a globally coordinated assessment, including the development of common monitoring indicators, and an internationally recognized and accepted lexicon to harmonize the diversity of terms and definitions. It also highlights the lack of balanced, integrated approaches to understanding the complex facets of rangelands and pastoralism together: social, economic, environmental and political.

At the same time, the IYRP Steering Committee was also exploring several options for gaining a UN designation and tried to work through different UN processes, including a Kenyan Government draft resolution that was to be presented directly to the UN General Assembly in New York. However, by the end of 2018, it became clear that such a proposal would need to first be presented...
and approved by the UN Food and Agriculture Organization (FAO) in Rome and that there were numerous steps to be taken before gaining FAO support.

To this end, at the UNEA-4 held in Nairobi, Kenya, in March 2019, the IYRP Steering Committee once more worked hard to build support for an IYRP. A special “Ministerial Breakfast” event was held on 12 March 2019 with significant support from the International Livestock Research Institute (ILRI) and UNEP. This resulted in UNEA-4 adopting a major resolution submitted by the Africa Group that, for the first time, explicitly called for recognition and support of sustainable rangelands and pastoralism. It acknowledged the findings of the Gap Analysis and recommended countries to carry out regional assessments. It also acknowledged the “ongoing global efforts to introduce a proposal for an International Year of Rangelands and Pastoralism to FAO’s Committee on Agriculture” (UNEA-4 2019).

A key result of the Ministerial Breakfast at UNEA-4 was that the Minister of Environment of the Government of Mongolia committed to obtaining inter-ministerial support for Mongolia to take the lead on an IYRP proposal to FAO. In July 2019, the Ministry for Food, Agriculture and Light Industries in Mongolia presented its formal intention to FAO and by October 2019 a full proposal for the IYRP designation had been submitted to COAG. By early 2020, letters of support from four countries and 26 non-governmental organizations had also been submitted to COAG. To provide ongoing leadership to the process, a National Working Group was established in Mongolia, consisting of representatives of all relevant ministries, NGOs and pastoralists. The IYRP Steering Committee then voted to change its name and nature to the IYRP Support Group (ISG) so as to acknowledge this important step.

In August 2020, a final proposal and letters of support were presented to FAO’s Committee on Agriculture (COAG) for discussion and a vote at the October 2020 COAG meeting. To raise the visibility of the initiative to COAG members, a collaborative effort launched a social media campaign and created a new IYRP website to act as an “online booth” including videos, images, and testimonials representing ten regions of the world. These efforts created a groundswell of support from 50 countries and more than 150 organizations that the authors believe greatly contributed to COAG’s endorsement of the IYRP proposal. This was quickly followed by endorsements from the FAO Council (December 2020) and the FAO Conference (June 2021).

Since then, the FAO Director-General submitted the request to the UN Secretary-General for deliberation and a final vote by the UN General Assembly which will be held toward the end of 2021. Upon proclamation by the UN, designated agency(ies), including in this case, FAO, UNEP, the International Fund for Agricultural Development (IFAD) and the U.N. Convention to Combat Desertification (UNCCD), would be mandated to facilitate the implementation of the International Year in collaboration with member countries and other relevant stakeholders, including research institutes, academia, civil society and the private sector. Linkages are also being made with related international initiatives as the International Decade of Family Farming and the International Decade of Ecological Restoration.

Rationale, Expected Outcomes and Outreach Plans of the IYRP

The rationale for an IYRP is:

- To increase worldwide understanding of the importance of rangelands and pastoralists for global food security and environmental services
- To call attention to the need for sustainable management and enlightened policy to benefit current and future generations

Many outcomes are expected from the activities to be conducted prior to and during the IYRP. Most of these will be at the country and local levels and will be planned and implemented by national committees. Examples include: expos, awards, fairs, educational materials, national awareness days, social media campaigns and video documentaries, etc. Pastoralist gatherings could be sponsored by the World Initiative for Sustainable Pastoralism (WISP) and the FAO Pastoralist Knowledge Hub to share local knowledge and strategize practical solutions.

At the global level, the SDGs specifically mention “pastoralists” and, therefore, through the relevant UN agencies, countries, will be encouraged to put forward an Action Statement for the next decade to ensure a sustainable future for rangelands and pastoralists. This could include launching actions by partners and partnerships at global, regional and national levels to change policies and increase development resources and political commitments.

International organizations and other global partners could consider “hosting” a theme throughout the IYRP. Relevant international conferences held during that year would be asked...
to commit to including a focus on rangelands and pastoralism. A future Joint International Rangelands and International Grasslands Congress could consider focusing on the most recent knowledge on key issues concerning rangelands and pastoralists. A wide variety of publications and articles in the popular press such as National Geographic and Smithsonian would be encouraged to broaden understanding of rangelands and pastoralist contributions to a healthy planet and people.

**Proposed 12 Monthly Themes for an IYRP**

A draft plan for IYRP outreach activities was developed by the ISG and includes 12 monthly themes (ISG 2017) based on the following criteria:

- Expanding awareness on the diversity of rangeland ecosystems and pastoral cultures
- Highlighting new insights, such as:
  - non-equilibrium (dynamic) nature of rangeland ecosystems; rangeland health as it relates to plant growth and use; the value of livestock mobility as it relates to rangeland health; and adaptation to climate change.
  - Identifying priority issues of concern to pastoralists
  - Balancing coverage of environmental, social, economic, and political issues

The ISG suggests that a period of wide consultation among all stakeholders should follow an IYRP designation to refine and finalize these themes. The advice of communications experts should be sought to fine-tune messaging for mass/social media. Because of the diversity of terminology (e.g. rancher vs herder), more work is needed to adapt the themes to successful forms of messaging including translation into international and local languages.

**Conclusions/Implications**

With ever increasing challenges facing pastoralists and rangelands worldwide (including degradation and conversion to other uses, as well as lack of appreciation of the role of rangeland ecosystems as climate solutions or of sustainable pastoralism’s contributions to production and conservation), it is vital that an IYRP be designated and that governments commit to making meaningful changes that benefit them. While the impetus for declaring such an International Year has come from the scientific, academic, and NGO communities, it has been gaining support from both pastoralists themselves and governmental agencies. Nevertheless, the role of the Continuing Committees of the IRC and IGC in helping to support the IYRP initiative remains vital for the next few years. With so many other topics in line for designation as International Years, it is important to understand that the value added of the IYRP is not just in raising awareness but in changing minds and, therefore, policies. For too long policies have been shaped by misunderstandings and misperceptions about rangelands (Are they just grazing lands? Are they just degraded forests?) and pastoralism (who?). It is time for substantive change!

**Acknowledgements**

Authors would like to thank the members of the International Support Group of the IYRP.
References


Panel 1: Topic: Land use/tenure and governance
Priority Areas for Action and Research on Pastoralism and Rangelands in Eastern Africa

Odhiambo, M.O.
People, Land and Rural Development (PLRD), Kisumu, Kenya

Key words: data; pastoralism; policy; rangelands

Abstract
There is an element of irony around pastoralism and research in Eastern Africa. While it is one of the most researched production and livelihood systems, pastoralism is also the least understood by policymakers and development actors, with discussions about its importance characterized by significant gaps in knowledge. Moreover, policy actors have difficulties accessing empirical data specific to pastoralism and rangelands in a form that allows well-founded decision-making on policy and action. Most available data tend to be outdated and not disaggregate with reference to pastoralism and rangelands. As a result, much of the discourse around pastoralism and rangelands is based on generalities and stereotypes dating back to the late 19th century, when colonialists first contacted pastoralists in Eastern Africa. These generalities and stereotypes are partly to blame for the persistence of inappropriate policy approaches to the development of pastoral areas in the region.

Empirical and up-to-date data are critical for making a case for targeted investment by governments and other development actors to support pastoralism and sustainable rangeland management in Eastern Africa, where rangelands constitute nearly 75% of the landscape and are home to up to 90% of the livestock population. In addition, such data should demonstrate the contribution of pastoralism and rangelands to livelihoods, food and nutrition security, alleviation of poverty and adaptation to climate change.

This presentation identifies key areas for action and research to fill the knowledge gap on pastoralism and rangelands in Eastern Africa. It highlights interventions that should be prioritized to address the challenges that pastoralists face in governance, land and natural resource management and development planning and create an enabling environment for sustainable pastoralism and rangelands management and development.

Introduction
This paper identifies the main priority areas for research and action to inform the creation of an enabling environment for pastoralism and rangelands in Eastern Africa. Based on a review of key literature and policy documents, the paper is premised on recognising two related facts. Firstly, notwithstanding significant progress in recent years, the policy, legal and institutional context in Eastern Africa continues to be largely unaccommodating for pastoralism and rangelands. Secondly, despite the fact that pastoralism is one of the most researched production and livelihood systems, government policies and programmes on governance, rural development and management of the land, environment, and natural resources display a huge knowledge gap on its logic, rationale and importance. In these circumstances, the need for research to strengthen the evidence base for policymaking cannot be overemphasised. ‘Eastern Africa’ is used in this paper to refer to the region covered by countries that comprise the East African Community (EAC) and the Intergovernmental Authority on Development (IGAD). The region is characterised by expansive drylands, which occupy nearly 75% of the landmass. The proportion of drylands in countries of the region ranges from 20% in South Sudan to 99% in Eritrea. Pastoralism is the predominant land use, livelihood and production system in these drylands, and pastoralists and agropastoralists constitute significant proportions of national populations. In addition, they produce 90% of the livestock in the region, contributing on average 57% of the agricultural Gross Domestic Product (GDP) in IGAD Member Countries.

Yet the importance of pastoralism and rangelands

1The specific countries of relevance here are Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Tanzania and Uganda.
to livelihoods and economies is not reflected in government policies across the region. Countries do not have policies that enable and facilitate the practice of pastoralism and sustainable management of rangelands. Where policies are adopted, they focus on production, paying little attention to processing and marketing (Mkama and Sulle, n.d.). Moreover, sector policies that have a bearing on pastoralism and rangeland management tend to contain adverse provisions that frustrate this livelihood and production system.

Critical policy-related challenges to pastoralism and rangeland management

Policy-related challenges to pastoralism and rangelands are many and diverse. The detailed manifestation of the challenges varies from country to country depending on a variety of factors, among them the national historical, ecological, demographic and political context. However, the challenges derive from policies adopted by governments in three major areas: political governance; economic development planning; and land, environment and natural resource management. In all three areas, the interests of pastoralism and rangelands are routinely overlooked and undermined by policy imperatives that aim to address concerns of majority populations in countries of the region. National policies in the region tend to contain prescriptions underpinned by either overt hostility or benign neglect of pastoralism and rangelands (Johnsen et al., 2019).

Political governance: history of marginalization

Although national contexts vary, in general, pastoralists as a group have tended to be victims of policies on political governance in Eastern Africa since the emergence of modern state systems during the period of colonial occupation, experienced by all the countries in the region other than Ethiopia. The preferential treatment of settled communities was dictated throughout the region by the logic of a colonial state apparatus using limited personnel and resources to impose authority over large populations in vast territories. With settled communities, colonial administrators made agreements and eventually entered into partnerships that morphed into post-colonial states.

Centres of power and commerce were established along the coastline, on the banks of the Nile River and the shores of Lake Victoria, and in highland areas where climatic conditions were more tolerable for colonial administrators and settlers. These areas were far from the rangelands where pastoralists lived and grazed their livestock. The patterns of white settlement would ultimately dictate the distribution of urban centres and political and economic development, laying the foundations for the marginalization of pastoralists from political and economic development that would last well into independence. In Kenya, Sudan, Tanzania, and Uganda, the interactions between government and pastoralists during colonialism until the end of the 20th century were defined by imperatives of containment rather than engagement (Odhiambo 2014).

The policy attitude to pastoralists and rangelands regarding governance meant that traditional institutions remained central to governance processes within these communities. However, with containment rather than positive engagement as the basis of interactions, the authority of traditional institutions was ultimately undermined by lack of legal recognition, as state institutions usurped their functions and powers. But this was more in form than in substance, as the actual presence of the state institutions on the ground was never adequate for the purpose, and they lacked legitimacy among local communities.

Economic development planning: inappropriate or no investments in the traditional livestock sector

The political marginalization alluded to above translated into the exclusion of pastoralists and rangelands from investments for economic development. The drylands were perceived to lack economic opportunities, and pastoralists were seen to be averse to entrepreneurship. Uganda.

The case of Kenya is instructive in this regard, as the national development policy blueprint, *African socialism and its application to planning in Kenya*, designated the rangelands occupied by pastoralists as low-potential areas and made the choice that development money would be invested in “areas having abundant natural resources, good land and rainfall, transport and power facilities and, people receptive to and active in development”, where it would yield the largest returns (Republic of Kenya 1965:46). This and similar policy biases condemned the pastoral areas to economic marginalization, as they were denied investments in infrastructure and social services that would spur economic development.

The perception that rangelands were lacking in economic opportunities was reflected in the neglect of the traditional livestock sector. Policies and institutional frameworks for livestock development focused on commercial ranching,

2 Popularly known as Sessional Paper No. 10 of 1965
even though it was (and still is) the traditional livestock sector that supplies up to 90% of the meat consumed in the region (Nyariki and Amwata 2019). In addition, governments across the region have long neglected to support the development of physical infrastructures such as roads, markets and abattoirs or veterinary services needed to facilitate livestock production and productivity.

Yet countries of the region are self-sufficient in meat and meat products. Still, they are also active participants in the export market, with Somalia, Sudan, Ethiopia and Kenya making substantial livestock exports to the Middle East, all thanks to the traditional livestock sector underwritten by pastoralists in the rangelands. Moreover, the growth of the livestock sector had happened despite rather than because of government policy, as evidenced by the fact that, even when it had no functional State, Somalia was still a lead exporter of livestock (Lesseon 2007).

**Land, environment and natural resource management: tenure insecurity**

Secure access to rangelands for grazing is central to the identity and sustainability of pastoralism as a system. Over time, pastoralists have developed institutions, systems and practices that enable them to make optimal and productive use of the unique ecosystem in the drylands of Eastern Africa. These include communal land ownership, seasonal mobility across landscapes that in some cases traverse national borders, and traditional institutions and systems for governance of natural resources. However, government policies have had serious challenges in accommodating these institutions, systems and practices, particularly mobility and communal land tenure.

The practice of mobility has defined policy perspectives on pastoralism as a system. It remains the most critical sticking point in the way government policies and other production systems interface with pastoralism and rangelands, not least because it offends the policy preference by African governments for settlement, whether through cultivation or urbanization (Little 1992; Horowitz and Little 1987; Galaty et al., 1981).

Mobility feeds the perception among policymakers and other land users that pastoral land use causes degradation and that the rangelands are ‘empty’, ‘unused’ or ‘underutilized’, and therefore available for appropriation and conversion to other uses, including settlement, large-scale commercial agriculture, infrastructure development, location of refugee camps and installations for military training and exercises. Furthermore, as populations have grown and land uses incompatible with pastoralism have increased in the rangelands, the potential for conflicts between pastoralists and other land users during pastoral mobility has equally increased. This leads to mobility being projected in policy circles as the cause of conflict and insecurity in the rangelands, resulting in policy responses that undermine pastoralism and sustainable rangeland management.

Government policies in the region have also had challenges in accommodating communal land tenure, given the privatization of land rights. Moreover, communal land tenure contradicts imperatives of state control of land and natural resources. The challenges have been exacerbated in recent years with the renewed focus on African land for large-scale commercial agriculture and other land-related investments, which has seen states in the region appropriate large portions of former rangelands and convert them to non-pastoral uses.

**Looking ahead: towards enabling policy environments**

A major challenge to policymaking regarding pastoralism and rangelands is that it is generally not informed by evidence. Despite the fact that pastoralism is one of the most researched production and livelihood systems in the region, there are still national policies that are not informed by research. As a result, perceptions about pastoralism among key policymakers and development actors and the general discourse about pastoralism and the rangelands – particularly within the popular media – continue to be based on generalities and stereotypes.

The negative perceptions and stereotypes are a major driver for the persistence of inappropriate policy approaches to the development of pastoralism and rangelands in the region. They result in little effort being made to generate empirical data specific to pastoralism and rangelands in development planning, which feeds the narrative that pastoralism and rangelands make little or no contribution to national economies and justify failure to allocate resources direct investment to the drylands. Where data exist, they are often out of date and thus not useful for informed decision-making on policy and action.

The need for empirical and up-to-date data on pastoralism and rangelands to form the basis for making a case for effective investment by governments and other development actors in pastoralism and rangelands cannot be overstated. Data are needed to demonstrate pastoralism and rangelands’ contribution to livelihoods, economic development, food and nutrition security,
environmental sustainability, and adaptation to climate change in the region. Some of the key areas for research and action to provide a better basis for strong advocacy and sound policymaking in Eastern Africa are shown in Table 1.

Table 1: Key areas for research and action on pastoralism and rangelands in Eastern Africa

<table>
<thead>
<tr>
<th>Priority areas for research</th>
<th>Priority areas for advocacy and policy action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The logic of pastoralism and their rangelands management practices (why pastoralists do what they do)</td>
<td>1. Capacity building for pastoralist civil society to engage with relevant national, regional and global policy processes</td>
</tr>
<tr>
<td>2. The value of pastoralism and rangelands for national, regional and global economies</td>
<td>2. Capacity building for governments and development actors to understand pastoralism and rangelands, their roles and potential</td>
</tr>
<tr>
<td>3. The contribution of pastoralism and rangelands to food security, regional peace and integration</td>
<td>3. Strengthening devolution of governance and natural resource management</td>
</tr>
<tr>
<td>4. The value of pastoralism and transhumance for productivity and health of rangeland ecosystems</td>
<td>4. Reinforcing capacity of governments and civil society for improved data collection, analysis and dissemination</td>
</tr>
<tr>
<td>5. The role/potential contribution of pastoralism and pastoralists’ indigenous knowledge to adaptation to climate change</td>
<td>5. Strengthening the interface between research, policy and practice with respect to pastoralism and rangelands</td>
</tr>
</tbody>
</table>

In the future, this agenda for research and advocacy should be linked to regional processes at the African Union (AU) and IGAD levels, where frameworks already exist for improved understanding and action in support of pastoralism and rangelands. The AU Policy Framework for Pastoralism (AU 2010) and the IGAD transhumance protocol (IGAD 2020) provide solid foundations for engaging governments collectively and individually for improved policy and programming in support of pastoralism and rangelands. Advantage should also be taken of good practice examples at the national level, particularly in Ethiopia, Kenya and Tanzania on some of these priorities.

Acknowledgements
The author would like to thank Dr Ann Waters-Bayer, who would not have seen the light of day without her encouragement and support in this paper. Thanks also to members of the Eastern & Southern Africa Support Group for the International Year of Rangelands & Pastoralists (IYRP), particularly Emmanuel Sulle, for helpful feedback on a draft of the paper.

References


Rangelands and pastoralism in Central Asia and Mongolia: challenges and perspectives

Ulambayar, T
Saruul Khuduu Environmental Research and Consulting, Ulaanbaatar, Mongolia

Keywords: rangelands; climate change adaptation; knowledge gap; multistakeholder support

Abstract
Livestock herding contributes 10-45% of national GDPs across the Central Asia and Mongolia (CAM) region while supporting the livelihood of nearly one-third of the region’s population. Over 171 million herds graze the region’s rangelands, occupying 65-73% of the territories in Central Asia (CA) and Mongolia. Traditional pastoralism has been affected dramatically by climate change. For the last decades, the annual mean air temperature has risen two to three times higher than the global average in CA and Mongolia respectively. Annual precipitation has a decreasing trend over the same period, causing increased aridity, a decline in lakes and rivers leading to a reduction in plant species and biomass production, an increase of barren areas. Extreme climatic events such as wildfire and drought—as well as a winter weather disaster called dzud—have increased in frequency and severity, causing livestock mortality and diminishing pastoral livelihoods. These trends have been observed across the region, where pastoral livestock husbandry remains an important economic sector while preserving the nomadic identity. However, most herders are insufficiently protected from climate-induced disasters left highly vulnerable to risks and external shocks. Hence, pastoral herders’ key adaptation strategies, including improving rangeland management by joining formal herder organizations, introducing more productive livestock breeds, improving livestock productivity, increasing essentials facilities, winter shelters, forage production, and well construction, require multi-level partnership and multi-stakeholder support. Only by addressing the existing gaps in knowledge and science, the Governments of Mongolia and CA countries will help tackle adaptation challenges faced by herders, including rangeland degradation caused not only by a warming climate but also by the failures in pastoral governance. The CAM states see the great opportunity for global partnership and actions by designating the International Year of Rangelands and Pastoralism (IYRP) to sustain pastoral heritage across the region for generations.

Keywords: Rangelands; climate change adaptation, knowledge gap, multistakeholder support

Introduction
The CAM region covers six post-socialist countries of 5,667,116 km² areas, spanning from the Mongolian Plateau in the east to the Ustyurt and Turgay Plateaus in the west (UNSTAT 2019). The geography of the region is extremely varied, including Great Gobi, Karakum and Kyzylkum deserts, the high mountain ranges of Altai, Tien Shan, the Pamirs in the CA with altitudes reaching 7439m, and foothill plains, steppes, and temperate grasslands. Isolated from the oceans and adjacent to the great desert’s location determines the region’s temperate continental climate with hot summer and cold winter. The mean annual temperature in Mongolia fluctuates between -8 to 6°C (Natsagdorj et al., 2017), while it ranges from 2°C in northern Kazakhstan to 18°C in Turkmenistan and southern Uzbekistan, and below 0°C in the mountainous regions (Chen et al., 2019). Vegetation varies by ecological zones in the CAM: major types in CA include forests (account around 1.5% of the vegetated area), grasslands (39.34%), crops (18.98%), shrubs (22.27%), and sparse vegetation (17.31%) (Jiang et al., 2017). Mongolia’s vegetation varies by altitude, rainfall, and soil type having alpine tundra (3.0% of total area), mountain taiga (4.1%), mountain steppe (25.1%), steppe (26.1%), desert steppe (27.2%), and desert (14.5%) (Hilbig 1995). Around 110.3 million ha or 71% of land area are covered by grassland, and about 9% are covered by forest or shrubland (NSO 2019).
The CAM region has a total of 77.6 million ethnically-diverse population: ranging from 33.5 million in Uzbekistan to 3.3 million in Mongolia (UNSTAT 2019). The agricultural sector contributes 5.2% in Kazakhstan, 7.5% in Turkmenistan, 18.5% in Uzbekistan, 20.8% in Kyrgyzstan, 23.3% in Tajikistan (Hamidov et al., 2016) and 15% in Mongolia (Banzragch et al., 2021) by providing high-value food, income, employment, and foreign exchange. Pastoralism is an important economic and cultural activity tracing back to prehistoric times (Kerven 2011) evolved from the millennia human adaptation to continental climate shaped by region’s geography. The CAM contains 171.2 million heads of livestock, including sheep (53%), goat (24%), cattle (18%), horse (5%), and camel (5%) (FAOSTAT 2019) that contributes key export products such as meat and cashmere. Pastoral practices in CAM countries have undergone dramatic socio-political changes from the 1930s, going through forced collectivization with livestock nationalization, increased crop farming and sedentarisation and decreased mobility (Mirzabaev et al., 2016) with prevailing agro-pastoralism in CA (Kerven 2011). All six countries became independent from the Soviet influence in the early 1990s, starting transition to a free-market economy with livestock privatization and the collapse of state cooperatives.

In CAM countries, the land tenure remains under state property, except that Kazakhstan allows some private ownership on a limited scale (Mirzabaev et al., 2016). Under prevailing state management, some countries formally allow longer-term use rights through land registration, certification, contract use, or lease to individual farmers/herders, groups/farms, companies, and state entities (Fernandez-Gimenez, 2006; Mirzabaev et al., 2016) by adopting state land regulations. As such, the land tenure systems are diverse across countries: in Kazakhstan, six types exist by land-agent category (from small village system to State Land Reserve Fund); three types in Tajikistan by land use rights; annual ticketing for pasture use by self-governing village bodies in Kyrgyzstan; and state cooperative or farmer association-managed system in Uzbekistan and Turkmenistan (Mirzabaev et al., 2016); and soum/district government management in Mongolia allowing leases of spring and winter camps to herder households.

**Challenges for CAM pastoralism**

The CAM pastoralism has been increasingly challenged by warming climate and rangeland degradation for the recent decades. Climate change displayed in the temperature rise, at the rate, approximately two (Jiang et al., 2017) to three times that of the global average (0.74°C) in CA and Mongolia, respectively (Banzragch et al., 2021) with slightly decreasing precipitation exhibiting spatially heterogeneous changes across the region. Studies identified that these variables have different influences on different vegetation types: with more serious degradation is observed in the Karakum and Kyzylkum Deserts, the Ustyurt Plateau, and the wetland delta of the Amu Darya (Jiang et al., 2017) and north-central and north-eastern Mongolia (Banzragch et al., 2021; NAMEM 2018). These factors adversely impact land productivity through soil moisture loss, soil salinization, and biomass decline which leads to increased risks for climatic hazards such as drought and dzud with livestock mortality and diminishing livelihoods (Chen et al., 2019).

The extent of the rangeland degradation in CAM countries has been disputed with conflicting results due to varying methods, perspectives, and the lack of regional-scale research (Jamsranjav et al., 2018; Robinson, 2016). Mongolia’s national rangeland health assessment conducted in 2016 found that 42% of rangelands was in a non-degraded “reference” state, 34.6% slightly or moderately degraded, and 23.1% severely or totally degraded (NAMEM 2018). A recent study of CA vegetation change found a significant increasing trend in vegetation growth in the eastern part, whereas a significantly decreasing trend was found in the western part of CA (Jiang et al., 2017) from the combined effect of reduced precipitation and increasing temperature. Shrubs and sparse vegetation in the southern part of the Karakum Desert Ustyurt Plateau and the wetland delta of the Large Aral Sea have been degraded due to human activities such as oil and gas extraction (ibid.). Similarly, in Mongolia, land areas under mining increased by 157% over the past decade (NSO 2019). In the absence of pastoral institutions, individual pastoralists undertake de-facto pasture management because they lack sufficient financial capacity for seasonal movement. These pastoralists also face difficulties for accessing remote pastures due to broken infrastructure such as bridges, roads and water supply causing overgrazing in village pastures and wintering areas (Robinson 2016). Therefore, both climatic and anthropogenic effects were identified as the main drivers of the rangeland ecosystem deterioration. These include increased livestock numbers concentrated near roads, settlements and markets, leading to overgrazing, shifting herd structure (more goats), loss of traditional rangeland management practices, decreased seasonal movements, and the lack of institutions...
for rangeland management, weak infrastructures, particularly watering points, and inadequate veterinary services (Fernández-Giménez et al., 2017; Mirzabaev et al., 2016).

**Key issues of rangelands and pastoralists in the CAM region**

To sustain economically viable food production, pastoral livelihoods, and cultures in the region, the following issues have to adequately addressed:

**Issues affecting rangelands and pastoralists**

- Lack of formal recognition of pastoralists’ customary institutions and land tenure rights;
- Insufficient regulatory and financial support to emerging community-based management institutions;
- Reduced herd mobility and seasonal pasture rotations leading to overgrazing;
- Unplanned and corrupted land use changes for crop cultivation, mining and infrastructure fragmenting rangelands;
- Overexploitation of rangeland resources for fuel, water extraction, timber production and pharmacology;
- Increasing conflict over rangelands among mobile pastoralists, state authorities, and crop farmers;
- Increased climate change risks: prolonged droughts, severe floods, frequent fire, dust storms etc.;
- Improper delivery of mobile services i.e., veterinary, health, education, energy, and water points;
- Declining herder populations resulting in aging and potential lack of generation turnover, loss of traditions
- Lack of financial support to enhance pastoralists’ contribution to the economy and food security;
- Infectious diseases as a threat to local breeds, livestock mortality, and transfer to humans.

**Knowledge and science gaps about pastoralism and rangelands**

- Insufficient research on regional-scale measuring changes in rangelands, vegetation, soil, and water
- Lack of social studies assessing pastoral institutions, pastoralists’ wellbeing, including access to services;
- Lack of appropriate recognition and integration of indigenous knowledge with modern science;
- Evaluation of impact of policies on rangeland restoration and pastoralists governance;
- Less attention to local livestock breeds adapted to climatic hazards risk;
- Lack of research about the economic viability of pastoralists and their contribution to food security;

**Actions proposed to conserve pastoralist’s territories at various dimensions**

- Acknowledge pastoralists customary territories through robust legal regulatory frameworks to prevent forced allocation of their lands to other purposes (development projects and green grabbing);
- Empower community-based rangeland institutions through participatory processes;
- Facilitate cooperation among researchers, governmental institutions and pastoralists to review policies;
- Lobby for awareness-raising about the importance of rangelands and pastoralists through IYRP;
- Develop a research agenda on the resilience of pastoralists and their contribution to food security;
- Create a dynamic map on the status of rangelands and pastoralists territories to conserve them worldwide;
- Assess the vulnerability of pastoralists production system to plan coping strategies with climate change;
- Support climate change adaptation strategies of pastoral communities (water harvesting, forage production etc.) towards strengthening the resilience;
- Encourage pastoral communities to establish their institutions based on their customary governance systems and recognize and support at various levels to play a key role towards sustainable pastoralism;
• Foster actions of community-based institutions to strengthen the mobility and rangeland management;
• Provide mobile services on health, education, veterinary, livestock breeding, etc. through extension services for higher productivity;
• Allocate financial resources for building capacity of young generations of pastoralists and provide incentives for entrepreneurship and innovations to encourage their stay in pastoralism;
• Incorporate pastoral production as one of the foundations of the local and national economy;
• Support pastoralists to save livestock genetic diversity and locally adapted breeds;
• Invest in strong advocacy on socio-ecological values on pastoralists among the general public to encourage pastoralists youth in conservation of their bio-cultural diversity.

Conclusion
The 5,667,116 km² portion of Eurasia across territories of the six countries of CAM is the largest contiguous dryland on Earth, providing a home to 77.6 million people and 171.2 million heads of livestock dominated by sheep and goats, critical for supporting pastoral livelihood and national economies. The CAM’s pastoral socio-ecological systems with thousands-years of rich heritage and cultural diversity has been challenged by increasing climate threats and anthropogenic impacts for the past several decades. The region has evolved from the same socio-political past, shifting from a centrally-planned socialist system to a free market economy. The CAM countries have increasingly faced the rangeland degradation partly because of the failure of state regulatory policies’, weakened rangeland management institutions, and the loss of customary governance systems which prevailed under neo-liberal free-market developments.

A priority for CAM states is to address key drivers of rangeland ecosystem deterioration and other contributing factors, in cooperation with the global community. This will help safeguard vulnerable pastoral communities’ wellbeing and protect a substantial portion of their national economies. In this context, the Government of Mongolia proposed a designation of an IYRP, which has been supported by 14 countries and 160 organizations and endorsed by the UN Food and Agriculture Organization’s Council.

The IYRP can support much needed global partnership and multi-stakeholder dialogues to tackle the complex systemic issues, promote and apply evidence-based experiences and pastoralists’ rich traditional knowledge. The CAM states acknowledge the need for building synergy among the multilateral policy instruments, to help legal recognition of pastoralists customary rights over their territories and rangeland resources. International instruments include the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) “Art. 31.1” and the Programme of Work on Protected Areas (PoWPA) of the CBD, Nagoya Protocol on Access and Benefit-sharing, the Land Degradation Neutrality (LDN) of the UNCCD.. In addition, the CAM countries can utilize the IYRP for developing regional strategy and action plan to reduce rangelands degradation and promote the pastoral way of life and stop any discrimination against pastoralists in the region.

Acknowledgements
The author thanks Dr. M. Niamir-Fuller, Prof. M. Fernandez-Gimenez, and Y. Hijaba for their constructive comments on the draft, and Dr. C. Kerven for sharing useful sources on CA rangeland studies.

References


Panel 2: Topic: Social/economics and demography
Rangelands and pastoralism of the Middle-East and North Africa, from reality to dream

Naghizadeh, N1; Badripour, H2; Louhaichi, M3; Gamoun, M3; and Niamir Fuller, M4

1Centre for Sustainable Development and Environment (CENESTA)
2Forests, Range, and Watershed management Organization (FRWO)
3International Centre for Agricultural Research in the Dry Areas (ICARDA)
4Vice-Chair of ISG of IYRP

Keywords: Customary; Governance; Recognition; ICCAs; Paradigm-shift

Abstract

The Middle East and North Africa (MENA) is a vast area covering 20 countries from western Asia to North Africa, with nearly 9,000,000 Km² and 303 million hectares of total rangelands. Rangelands play an essential role in supporting people’s livelihoods and food security. Mobile pastoralism is the most viable and resilient form of production and land use in the fragile drylands of MENA. However, the region’s governments have considered nomadic pastoralism backwards mainly because it was challenging to deliver mobile services. They designed various policies that were not in harmony with pastoralists’ customary rules and norms and severely weakened their mutual aid associations and governance systems for natural resources management. Nowadays, pastoralists’ rangelands and customary territories are shrinking, fragmenting, and degrading due to various reasons, but mainly the expansion of agricultural or industrial needs. Based on pastoralists and rangelands’ socio-ecological values, the world needs to apply the evidence-based experiences and Indigenous knowledge of pastoralists in preventing rangeland degradation. It is urgent to start a new paradigm shift for an inclusive interaction, establishing pro-poor livestock policies. These policies would address the barriers and bottlenecks faced by pastoral and agro-pastoral communities and secure land tenure at community and landscape levels through multi-stakeholder dialogue, including during the International Year of Rangelands and Pastoralists (IYRP). It is time to call for respect of customary governance systems of pastoralists, recognition of their territories as Indigenous and Community Conserved Areas (ICCA’s—territories of life) under various and norms in the region like Qoroq, Hima, Agdal, and any other form of local conservation to prevent fragmentation of pastoralists territories and rangelands degradation leading to desertification.

Introduction

The MENA region covers 20 countries from western Asia to North Africa with nearly 9,000,000 Km². Algeria is the largest, and Bahrain, an island in the Persian Gulf, is the smallest country in the MENA region. Out of 5.3 billion hectares of rangeland globally, 303 million hectares are located in the MENA region (Asadian et al., 2016). In terms of topography, it is quite variable. In the north, the region is ringed by several important mountain ranges. Lesser chains of hills and mountains extend along with the coastal areas of the eastern Mediterranean. The region enjoys a wide range of elevation from −417 m Above Sea Level at the Dead Sea in Jordan to 5,610 m ASL at Mount Damavand in Iran. The Mediterranean bio-climate affects the region, characterised by a long, semi-hot, dry summer, and cold, rainy and snowy winter, and enjoys an arid and semi-arid climate with low and erratic rainfall. However, the vicinity to the sea and the topographic characteristics mean that some humid areas can be found close to desert areas where annual precipitation is less than 100 mm. More than 50% of countries’ land area is very dry, except Lebanon, Morocco, and Tunisia. Almost 83% of other Near East countries are in arid and desert zones. Existing vegetation results from a long history of human activities and ecological conditions: climate, topography,
and soil. The Middle East’s dominant vegetation types are steppe and deserts that belong to the Irano-Turanian botanical province consisting of Chamaephytes and hemi-phytes.

The MENA is the origin of livestock’s domestication, practised through mobile pastoralism, pastoralists who search for feed and water and escape harsh climates. Based on the latest census, 419,116,760 people live in the MENA region (Wikipedia-population of MENA Countries). The percentage of rangelands of countries in the MENA region varies from 0% in Bahrain to 33% in Tunisia to more than 50%, Iran (52%) and Jordan (90%). The land tenure system has been one of the region’s major constraints of rangeland management. Rangelands are grazed free of charge for enduring religious and cultural reasons. Rangeland boundaries and grazing territories are not determined or assigned to village communities or tribes. Despite laudable attempts in several countries, in the absence of a proper and clear land tenure system, today’s users have no incentives to invest and manage properly rangeland resources used on the “first-in, first-served” principle.

Land tenure in the region has its origins in state, customary or religious law, or more often, a combination of the three. In some countries like Tunisia, privately owned rangelands remain important (28%). The traditional tenure systems across the region have largely changed within the constructs of colonialism and the nation-state. These constructs hamper management policies and strategies because of the limitations of generalities. Thus individual country studies are highly needed to prepare a clear picture of what is going on in each country. For pastoral communities, access to natural resources is a vital means of generating livelihoods and accumulating wealth and transferring it between generations. Therefore, how land rights are perceived will have a significant bearing on the family’s ability to meet subsistence, supply income, in cases establish status, make a non-observable effort, and make investments. Local people live in a complex legal system and will often be motivated by various legal sources other than “official” law, such as religious and customary law. “Locality” and the conceptual framework of “legal pluralism” are key notions of an emerging paradigm adopted here on the relations between law and social behaviour.

Historically, property rights in the official law of the region have coupled Islamic principles and customary laws with the state’s or ruler’s demands to secure rights. State power tended to dissipate beyond the seat of governments. For a long time, the state’s formal legal system, the qanun, co-existed with customary law, ‘urf. Whereas the qanun was by definition written, the ‘urf was largely unwritten. To some degree, the qanun often confirmed existing local customs. Simultaneously, it has also been recognised that custom is one of the sources of Islamic law; shari‘ah, itself a pillar of the qanun. With the ascendancy of the nation-state, official legal systems sought to entrench sovereignty overland with the abolition of customary law and the evolution of shari‘ah to deal with modern needs of economic development. Often this has meant a degree of secularisation in property rights.

Indigenous and Community Conserved Areas (ICCA) — Territories of Life Phenomenon

“ICCA—territories of Life” is the name proposed to explain the situation when community-territory association is combined with effective local governance and conservation of nature (Borrini et al., 2016). Pastoralists’ history of nature conservation dates back to thousands of years based on their strong social organisation, identity, collective production, and adaptation of their governance systems to complex ecological conditions in different ecosystems (Naghizadeh et al., 2012). In most indigenous cultures, it is possible to find a phenomenon that is so strong and natural to be nearly invisible. Since the beginning of the second millennium, this phenomenon has been purposefully singled out as one of humanity’s essential features, in jeopardy because of current social and ecological change. ‘ICCAS’ refers to this age-old, widespread, diverse, dynamic phenomenon, territories, and areas conserved by indigenous peoples and local communities. Worldwide, there is a wide variety of ICCAs, differentiated based on ecological, socio-cultural, political, and economic features, such as Aq`dal in Morocco and Tunisia, Qoroq in Iran, Hima in the Arabian Peninsula, and adjacent countries such as Syria and Jordan. This is a traditional practice regulating access to grazing lands to support the restoration of natural resources, which can be defined as a seasonal prohibition. It is the most widespread and longstanding Indigenous conservation institution in the MENA region and perhaps on Earth. In the last decade or so, the ICCAs have gained significant recognition at international and national levels by IUCN, Convention on Biological Diversity (CBD), UNESCO Intangible and Cultural Heritage, and indirectly through a range of international human rights, agricultural, development, and other instruments. Despite the visible progress in
recognising and supporting ICCAs, there remain huge weaknesses and gaps - most countries have no or very inadequate legal and policy mechanisms to respect Indigenous peoples and local communities (especially concerning territorial, collective, and tenurial rights). In many regions, the existing policy environment works against the interests of mobile pastoralists (Kothari et al., 2012).

Key issues of rangelands and pastoralists in the MENA region

Pastoralists are important societies through their vital role in food production in the MENA region. However, nowadays, various issues threaten their existence as follows:

Issues affecting rangelands and pastoralists

- Lack of recognition of pastoralists’ customary governance systems and land tenure rights;
- Forced and induced sedentarisation and nationalisation of natural resources;
- Weakening of pastoralists’ sense of ownership has caused unsustainable use of the rangelands;
- Conflict over rangelands among mobile pastoralists, state authorities, and settled communities;
- Fragmentation of pastoralists’ territories and rangelands degradation due to land-use change;
- Climate change consequences such as severe floods, recurrent and prolonged droughts, etc.;
- Improper delivery of mobile services, i.e., veterinary, health, energy, water points, education;
- Lack of financial support to enhance pastoralists’ contribution to the economy and food security;
- Transboundary diseases as a threat to local breeds and livestock mortality.
- Knowledge and science gaps about pastoralism and rangelands
- Insufficient research on socio-economic and ecological values of rangelands and pastoralists;
- Lack of appropriate recognition and integration of indigenous knowledge with modern science;
- Evaluation of the impact of inappropriate policies on rangelands restoration and pastoralists governance;
- Lack of documentation of good practices on ICCAs—territories of life such as Hima, Aqdal, Qoroq, and other traditional conservation approaches by pastoralists;
- Less attention to local livestock breeds adapted to climatic hazards risk;
- Lack of research about the economic viability of pastoralists and their contribution to food security;
- Actions proposed to conserve pastoralists territories at various dimensions
- Advocate for legal recognition of pastoralists’ customary governance and land tenure systems;
- Empower pastoralists customary governance institutions through the self-strengthening process;
- Build trust among researchers, governmental institutions and pastoralists, and alliances for participatory review and reversing inappropriate policies;
- Lobby for awareness-raising about the importance of rangelands and pastoralists through IYRP;
- Create a research agenda on the resilience of pastoralists and their contribution to food security;
- Recognise pastoralists’ customary territories, through robust legal frameworks, to prevent allocation of their lands to other purposes such as large-scale development projects;
- Develop a dynamic map on the status of rangelands and pastoralists territories with the aim of legal and practical conservation of pastoralists territories worldwide;
- Support adaptation strategies of pastoral communities to climate change issues (such as seasonal migration) and strengthening their internal resilience systems;
- Assess the vulnerability of pastoralist’s production systems to cope with climate change;
- Support pastoral communities to establish their institutions and coalitions based on their customary governance systems and recognition at various levels to play a key role towards sustainable pastoralism;
- Establish self-organised funds and institutions to strengthen the mobility of their life through various innovations in sustainable pastoralism and land management initiatives;
• Provide mobile services on health, veterinary, education, etc. to sustain their way of life;
• Build capacity of pastoral youth and allocation of financial resources and incentives for entrepreneurship and innovations in support of sustainable pastoralism;
• Incorporate pastoral production as one of the foundations of the local and national economy;
• Share experiences and mutual learning between pastoralists at various levels;
• Support pastoralists to save livestock genetic diversity and locally adapted breeds;
• Invest in strong advocacy on socio-ecological values on pastoralists to encourage pastoral youth to conserve their bio-cultural diversity.

**Conclusion**

Considering the critical value of pastoralists and rangelands in different dimensions, the world needs to take action. Action on multi-stakeholder alliances and dialogue to document, expand and apply the evidence-based experiences and indigenous knowledge of pastoralists in preventing rangeland degradation. Increased rangeland degradation is the last call for an urgent change of policies and actions toward strengthening pastoralists’ governance institutions and legal recognition of their vital role in restoring and conserving fragile rangelands ecosystems worldwide. A paradigm shift is needed to overcome the knowledge and policy gaps—particularly changing typically expensive and inefficient governmental bureaucratic range management systems to territory-based sustainable range management and appropriate integration of indigenous knowledge with relevant modern science to manage rangelands.

The IYRP could provide a forum to debate and advocate the customary rights of pastoralists over their ancestral territories and natural resources. Various best practices and examples of traditional approaches in various ICCAs can demonstrate effective governance approaches. Another important priority is building synergy among the existing international policy instruments to enhance legal recognition of pastoralists’ customary rights over their territories and resources at various levels. The policy instruments such as The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) “Art. 31.1”; the Programme of Work on Protected Areas (PoWPA) of the CBD; the Nagoya Protocol on Access and Benefit-sharing; and the Land Degradation Neutrality (LDN) of the UNCCD. The IYRP can help develop a strategy and action plan to alleviate rangelands degradation and stop discrimination about pastoralists’ society in different dimensions. This can be done by strengthening their customary institutions via renewed self-strengthening, internal cohesion, and more powerful coalitions and federations at various levels. Supporting the establishment of pastoralists associations and federations will likely help them stand up as legally recognised actors, for effective dialogue and collaboration with state agencies and capable of playing a significant role in policy influence and decision-making processes.

**References**


Action Plan for the International Year of Rangelands and Pastoralists (IYRP): The Case for the United States, Canada and Mexico

Barry Irving, 1 Larry Howery, 2 Jürgen Hoth, 3 Jess Peterson 4

1 Retired Director of Agricultural Research Stations, University of Alberta, Canada
2 Professor and Extension Range Specialist, The University of Arizona, USA
3 Vice President Fundación Biósfera del Anáhuac, A.C., Mexico
4 Executive Vice President, Society for Range Management, USA

Key words: United Nations; international year; United States; Canada; Mexico; rangelands; grasslands

Abstract
The GAP analysis (A Case of Benign Neglect: Knowledge gaps about sustainability in rangelands and pastoralism) points to several gaps that are relevant to the US, Canada and Mexico. North American rangelands span the ecological continuum of polar to hot deserts and arid to humid climates that exhibit highly variable ecological and forage production potential across time and space. Although there is a great deal of rangeland research, extension, and inventory capacity in all three countries, a weak link is the dissemination of information to North American pastoralists (conventionally referred to as ranchers or producers). Although the extension system in the US and Canada are similar, there are distinct differences. Public lands in the US are managed at the national level by federal agencies (e.g., Bureau of Land Management and Forest Service) while private land management assistance is provided by the Natural Resource Conservation Service. In Canada, Crown land is managed by departments within each province and there is no national extension service. In Mexico, the majority of the lands are managed by local communities or ejidos, 15% are privately owned and managed and the remaining 5% is government owned. The three countries support national research organizations and have a well-developed system of colleges and universities that have range management or related disciplines containing staff that specialize in teaching and/or research (and cooperative extension at land grant universities within the US). All three countries must attempt to bridge gaps between an urban industrial society that is increasingly disconnected from extensive agricultural production on rangelands. Promoting ecological goods and services provided by rangelands is a relatively new paradigm for US, Canadian and Mexican research and extension. During the IYRP, the focus in the US, Canada and Mexico is likely to be in 2 directions; providing North American pastoralists/ranchers with the social license to continue to ranch or farm while educating the massive urban population about the sustainability, multiple uses, and benefits of ecological services produced on rangelands and native grasslands.

Introduction
The United Nations Environment Programme Gap Analysis (Johnsen et al., 2019) will act as a backbone for an International Year of Rangelands and Pastoralists (IYRP). It contains a general description for the United States, Canada and Mexico about gaps in information and resources required for the wise use and stewardship of rangelands. Prior to focusing on a GAP or group of GAPS it is important to understand the evolution of sustainability of North American rangelands and pastoralists/ranchers. Although there are several ways in which sustainability can be classified a conceptual discussion for the US, Canada and Mexico can be framed through the following sequence:

1. Production
2. Ecological
3. Social and Cultural (local community)
4. Societal (national and/or global)

The Search for Sustainability of North American Rangeland
Historically, production, ecological, and social
and cultural facets of rangelands and pastoralists/ranchers have been sustained on a local scale. North America has developed in the last 500 years with a colonial philosophy that resulted in dramatic change from a mosaic of basic subsistence and sophisticated surplus based Indigenous societies to an agricultural production-based society dominated by people of European origin. African Americans and Indigenous peoples also contributed significantly to the development of North American ranching despite widespread discrimination (Katz 2019). An expansionist colonial ideology and perceptions of open land with almost unlimited production capability led to violent removal and subjugation of Indigenous populations followed by an explosion in livestock numbers throughout the western states and provinces, as well as throughout Mexico. Due to unregulated open access to grazing resources, and investment of foreign capital that incentivized mismanagement, overstocking at the end of the 19th century resulted in overgrazing, loss of production and ecological capacity to such an extent that sustainability of a fledgling livestock industry was uncertain (Specht 2019). The majority of the damage to rangelands during this time was in the more arid and semi-arid regions of the United States west of the 100th meridian and Northern Mexico. Canadian and northern US rangelands were also overstocked, but the damage was mitigated somewhat by severe winters (livestock numbers were controlled) that were not a factor at lower North American latitudes and by the relatively shorter time frame of exposure because European invasion and settlement occurred at a later date. Range management as a discipline originated in the early 1900’s.

The first goal of rangeland research was to reverse the downward trend in rangeland productivity and condition and return damaged rangelands to a suitable level of production. Stocking rate restrictions in western North America through legislative control probably occurred first in Canada. In 1881, through an Order in Council the Canadian government established a grazing lease system that was applied immediately to rangelands along the eastern slopes of the Rocky Mountains, in what is now southwestern Alberta. The lease system established the initial framework for leases throughout western Canada. Stocking rates, although high by present standards, were controlled by legislation and regulation. The Taylor Grazing Act provided the first permitted grazing leases and regulation of stocking rates in the United States in 1934, about the same time that control of natural resources was transferred from the Canadian federal government to the provinces in 1930. The management of the majority of public land rangeland in the western US has continued to be administered at the federal level mostly through the Department of the Interior (Bureau of Land Management and National Park Service) and Department of Agriculture (Forest Service). Canadian rangelands continue to be administered at the Provincial level. Stocking rate control and a grazing permit system administered by a government agency are strengths of North American regulatory systems. Length of lease tenure may be used as an incentive, reward, or penalty as deemed appropriate. Large scale rangeland assessments carried out in the mid 60’s in Northern Mexico (CFAN 1965) reinforced growing concerns related to land degradation through overgrazing. These drivers, operating also in South and SW USA, led to ecosystem level shifts from perennial grasslands to desert scrub since the mid 1800’s. Despite Mexico’s federal response of establishing carrying capacities, “índices de agostadero,” the condition of grasslands has continued to decline, together with the rampant (largely illegal) land use change to crops (Poole et al., 2014).

Production stability of North American rangelands has improved slowly but steadily from the lows of the late 1800’s. Improvements in production sustainability resulted in concomitant improvements in ecological sustainability. Research emphasis and extension into the pastoralist/ranching community from a more ecological viewpoint coincided with the founding of the Society for Range Management in 1948 (Sayre 2016). Research on the interaction of livestock grazing on watersheds and wild ungulate herbivores appeared in research journals in the 1950s. The discipline of Range Management adapted from a focus on improvements in production and began to take on the second prong of its character, ecological sustainability. That trend continues today, with more difficult to measure ecological contributors to rangelands becoming drivers of adaptive management decisions over time. This includes bird censuses that track grassland birds revealing their steep decline, an ominous sign for this ecosystem shared by all three countries. This worrisome trend has led to various binational and trinational multi-sectorial initiatives (e.g. Gauthier et al., 2003; Guzmán et al., 2012), the latest being the Grasslands Roadmap www.grasslandsroadmap.org. Past research and extension focus on reducing soil erosion has been augmented with current interests in the influence of soil microbiology on rangeland productivity and sustainability. Rangeland ecological research and extension have followed a scale trend from large, visible, and largely economic to small, difficult to measure and quantify, and in some
cases where an obvious economic linkage has yet to be shown.

Throughout both the development of rangeland management and the use of knowledge by the North American ranching community there has also been an evolution in local social and cultural networks (local community). Early on, many Indigenous communities incorporated European-origin livestock into their cultures and economies (Iverson 1994) while Hispanic communities maintained distinct cultural, land and livestock management traditions in the southwest (Peña 1999). African Americans brought livestock knowledge from Africa, helped establish ranching in the southeast (Sluyter 2012), and later founded numerous communities on the Great Plains, though many did not survive the Depression, Dust Bowl, and discrimination (Katz 2019). Euro-American family ranching evolved in the late 19th and early 20th centuries, displacing existing Indigenous communities. Community pillars that were once dominated by ranch families and staff (churches, community leagues, equipment dealerships, schools, eateries, etc.) have in some cases ceased to exist or amalgamated or assimilated into larger but farther apart entities.

As North America has developed the influence of agriculture in general and ranching in particular has declined. During the last century, urban populations have increased at a rapid rate, and even if rural populations have remained stable, which few have, the population has shifted to become urban, urbanized, and/or industrialized. Agriculture in Canada and the United States contributes 2.1 and 1.2% of the national GDP, respectively, while this sector represents slightly over 4% of Mexico’s GDP (Trading Economics 2021). Change, and the need to adapt to change by North American ranchers, including the aging and de-population of rural areas, has led to the development of the social science and environmental side of range management by most western and Mexican agriculture-related universities as part of their academic core. That was not the case at the dawn of the discipline when producing and selling maximum pounds of meat from rangelands was often a primary goal.

Despite a wealth of knowledge generated by the North American rangeland scientific community (e.g. Derner and Augustine 2016; Gauthier et al., 2003) and extended to the ranchers through various agencies, associations, and NGO’s at national to local levels, rangelands and ranchers are suffering from a wide variety of challenges. Invasive plants and animals, industrial disturbance, fragmentation, cultivation for annual crops and urban creep are a few examples of current problems that will affect rangeland productivity and ecological balance into the future. Complex interactions between all these factors and the short and long-term trajectories of climate change will require a continued and continual research and extension focus throughout US, Canada and Mexico’s rangelands. Although the issues vary by region, climate change will be a central theme driving research and extension.

A relatively recent focus regarding ranching communities is carbon sequestration. Throughout most of the settlement history in North America individual rangeland managers have mostly been concerned with challenges that are relatively local in extent and they adapted their operations to those local conditions based on local and traditional knowledge, applicable research and extension. Climate change and in particular the production of greenhouse gases (mainly through ruminant fermentation for rangeland livestock) and the potential to mitigate challenges in the atmospheric carbon cycle through carbon sequestration in rangeland soils and vegetation has burst into prominence. North American society is currently engaged in an active discussion that is pushing towards a choice between a demonstrable sustainable land use practice (grazing livestock on rangeland) and a new global paradigm that livestock grazing in general has negative effects on the earth’s carbon cycle and the earth’s climate.

This brings the discussion to the 4th level of sustainability; national and/or global societal impacts on pastoralists/ranchers from Canada, the US, and Mexico and to what will likely be a focus in preparations and outcomes for the IYRP. Although the North American system of rangeland research, extension, and advanced education has produced tangible effects on the sustainability of rangelands and pastoralists, there are structural issues. Cuts in funding at all levels has been a common practice in the three countries. Former Departments of Range Science in universities have amalgamated with Environment or Agriculture as they cannot stand alone in the current funding models. Range research stations have closed or been downsized, and extension agencies have been reduced, eliminated, or absorbed. An extreme example of this has played out in Canada in the last 10 years. The Prairie Farm Rehabilitation Administration, the Canadian equivalent of the Natural Resource Conservation Service was closed in 2012 after a series of cuts and absorption the previous 5 years. Although there are also cuts and vacancies in research, management, and extension positions in the US, the degree of change from the past appears to be thus far less than in Canada.
Reduced resources for range management throughout North America is happening at the same time when global concerns about the environment and the effect of agriculture on the environment are rapidly increasing. Public interest in ecological goods and services (EGS) and especially carbon emissions, sequestration, and atmospheric cycles is increasing. North American ranchers face a new and powerful detractor or opportunity, one that is taking the discussion directly to the urban consumer. Ranchers and farmers produce far more meat products than they consume; they are net exporters of food, mostly to urban areas within the continent. Although the US does export a small portion of its domestic beef production, it imports about the same amount mostly from Canada and Mexico (CEC 2015). Market availability to ranchers is where past similarities between Canada and the US are likely to diverge, mostly because of the difference between populations (the US has about 10x the population that Canada has) and the size of the livestock industry in each country. Cattle population in western Canada is much larger than the demand for beef, meaning western Canada is export driven in terms of markets for beef; beef exports hover around 50% of production. All North American ranchers are subject to a marketplace that is mostly urban, with areas of low local human population but a large rangeland area (and therefore large red meat production) being most susceptible to a changing marketplace.

**The Immediate Future**

To varying degrees future research and extension directions will likely be largely driven by EGS. Of course, red meat production is an EGS and has a long history of sustainability and an equally long history of research, teaching (university and college level), and extension. But carbon, and to a lesser extent other EGS, are driving current narratives for the importance of rangeland sustainability. The knowledge system on rangelands will likely be driven by ranchers (as in the past) but increasingly to respond to or challenge information being spread to the urban majority, who are the consumers of most red meat. It is a challenge for North American ranchers because they are engaged in a media scrum with a subset of the urban side of the population, the same demographic that is their primary marketplace. When the urban environmental movement points to the destruction of ecosystems that is eminent due to cattle ranching the livestock industry counters with messages showing how essential their industry is to rangeland sustainability (Irwin 2019). Hence, there is an opportunity for ranchers and pastoralists to promote the inherent value of proper rangeland management for sustainable livestock production in balance with multiple EGS. This will and has led to yet another term common in US and Canadian media: social license to operate. Social license to operate for the North American rancher is not a legal term; it bears little similarity to legal rules of rangeland use such as grazing dispositions on public rangeland or rigid standards put on the meat production chain. Social license is determined by the consumer and their willingness to purchase products. The consumer can and does choose alternate products based on their perceptions of the environmental sustainability of that products production process. Currently in North America there are numerous rangeland ranchers already engaged in capturing market share from an informed consumer base. The challenge for the informed consumer base is acquiring its information from a variety of sources, not all of which follow scientific rigor in developing conclusions. A common example is the proliferation of organic, ethically raised, regenerative agriculture (term implies that anything not claiming this label is suddenly ecologically damaging), and a myriad of other terms used to market to a niche portion of the consumer population. Recently, carbon sequestration has been a major topic in the social license to operate debate. Claims of healthier food resulting from organic production methods have not been conclusively proven in scientific literature (Novella 2016), proof of claims of regenerative agriculture resulting in 4-5 fold increases in soil organic matter (carbon sequestration) have been elusive (Ghosh and Mahanta 2014), and the advantages of grass-fed beef (higher polyunsaturated fatty acids (PUFA) and omega-3 fatty acids) are not enough to result in significant improvements in human health (Novella 2016). It appears that North America is at a time and place where extension and science are not always aligned. Although marketing claims may be proven by future research many current claims that are presented to and absorbed by the consuming public are ambiguous from a scientific standpoint.

**Conclusion and Implications for an IYRP**

There has been a long history of scientific study, extension, and instruction in sustainability of North American rangelands and pastoralists/ranchers. Rangeland Management as a science developed from a time of drastic overuse of rangelands and degradation in the late 19th and early 20th centuries. North America has moved through eras where production from rangelands, ecological stability of rangelands, and maintenance of ranchers social and cultural
lifeways have been major topics of interest for research, extension, and education. The current situation is one where an interesting dichotomy exists between past pillars of sustainability and urban consumers which in the end may negatively impact the sustainability of ranchers and farmers. A reasonable conclusion might be that when marketing becomes a dominant avenue in rangeland extension an increase of scientific studies might hopefully become common place. The future, and a major general topic for an International Year of Rangelands and Pastoralists from a North America standpoint might be a catchup phase, where science and extension will either enforce, support, or deny current trends evident in marketing of goods and services from rangelands. The future will likely involve integrating and balancing the nexus of extension and science to support pastoralists’/rancher’s science-based social license to sustainably provide economic and ecological goods and services on the largest land type (rangelands) in the world.

Acknowledgements
The authors acknowledge the contributions and constructive edits of María Fernández-Gimenez (Colorado State University), Anne Gondor (University of Arizona) and Elena Dosamantes (University of Arizona) and one anonymous reviewer from the IGC/IRC.

References


THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES

Topic: Local Knowledge, Local and Global Action
Valuing the expertise of mobile herders in arid South Africa- a photographic essay

Cupido, C.F1; Ellis, W.2; Samuels, M.I.3

1Agricultural Research Council – Animal Production: Range and Forage Sciences; 2Department of Anthropology and Sociology, University of the Western Cape; 3Department of Biodiversity and Conservation Biology, University of the Western Cape

Key words: pastoral; herders; Namaqualand; photography

Abstract
Pastoralism has been practised for millennia in numerous ecosystems across the world. However, throughout history, pastoral systems and herding have been replaced by the commercialisation of livestock production, which essentially made herders redundant in many sub-Saharan countries, resulting in job losses. Herding is, however, still practised in many countries, but the essential role of the herder is in many instances snubbed upon and disregarded as trivial work, hence their low social standing within the community.

However, the literature indicates that herding offers many benefits over commercial paddock systems, e.g. improving rural livelihoods, reviving the customary practice, reducing stock theft, reducing predation, and improving biodiversity management. The contribution of herders is often underestimated, even within livestock-keeping communities, but is, in fact, much more complicated, and they do far more than meets the eye. This paper (in the form of a photo essay) is an attempt to give a human face to herders through a series of photographic images and highlight particular activities of herders in the semi-arid Namaqualand region of South Africa. The images show the complexity of herding, which is an artisanal task. It depicts herders in their daily activities as botanists with in-depth botanical knowledge, including taxonomy, phytochemistry, nutritional value, toxicity, cultural, and ritual value. It also depicts herders as midwives during lambing season, practising nursing, and shows the interaction with their guarding dogs.

Furthermore, the images illustrate the gender identity with shepherdesses functioning in an extremely harsh semi-arid landscape. It also shows the interaction between herders at the water point, which acts as the gathering point for exchanging knowledge between these artisans. These results show that the value of herders in dryland farming systems deserves more recognition, and they should be key players in policy development.

Introduction
Pastoralism originated during the Neolithic period on marginal lands unsuitable for arable farming. The first traces of pastoralism in Africa dates back to around 9 000 BCE in the Sudan region. By the 17th and 18th centuries, pastoralists settled in the Southern African region around livestock kraals, and they moved seasonally to sustain the feed requirements of their livestock. Pastoralists adopted a transhumance strategy with flat-tailed sheep breeds and cattle within reach of grazing and water resources. Their movement into the winter rainfall zone of South Africa benefited the milch pastoral practices of the Khoekhoe (Russel, 2020) as it allowed them to occupy and move between the winter and summer rainfall region. In addition, this transhumance movement offered them access to good grazing throughout the year. However, the colonisation of South Africa resulted in land tenure, economic ideologies and government policies. This, in turn, led to the degradation or destruction of traditional lifestyles, culture and language of the Khoekhoe. As a result, transhumance movements had to be abandoned or restricted (Hoffman and Rohde 2007) and altered within the boundaries of mission stations (Samuels 2013), such as the Leliefontein and Steinkopf Communal Areas in Namaqualand.
Pastoral systems, particularly herding, have been replaced by the commercialisation of livestock production, which essentially made herders redundant in many sub-Saharan countries leading to job losses. Herding is, however, still practised in many countries, but the essential role of the herder is in many instances snubbed upon and disregarded as trivial work. Herders, therefore, have a relatively low social standing within the Namaqualand communities. However, Salomon et al. (2013) indicates that herding offers many benefits, e.g. improving rural livelihoods, reviving the customary practice, reducing stock theft, reducing predation, and improving biodiversity management. Similarly, Schlecht et al. (2020) describe herding as a multifaceted occupation with the key purpose of ensuring suitable nutrition of the flock by (1) directing livestock to nutritious grazing areas and water points, (2) preventing crop damage, (3) keeping them separated from other herds, (4) caring for new-born animals, (5) milking of lactating ewes, and (6) protecting the herd from predators and stock theft. The definition in itself illustrates herders’ dependence on a diverse and collective knowledge system to fulfil every aspect of the occupation. This paper aims to illustrate that herding is a complex and multifaceted profession that relies on an array of knowledge systems to successfully raise livestock within harsh and variable arid and semi-arid environments. Visual anthropological techniques were used in still photography to capture and illustrate the complexity and multifaceted characteristics of the herding profession.

**Study Site and Methods**

The study sites are located in the Namaqualand region, which stretches along the northwestern part of South Africa. The inhabitants of Namaqualand are descendants of the Nama-speaking Khoikhoi pastoralists who lived a transhumance lifestyle within this area before colonisation. Our focus for this study was within the Leliefontein Communal Area, which extends over the Kamiesberg mountain range with approximately 192 000 hectares and the Steinkopf Communal Area, which is estimated to be more than 500 000 hectares in size. Both areas form part of the winter rain-fed Succulent Karoo biome, which is renowned for its richness in plant biodiversity and the summer rainfall area of the Nama Karoo biome, which is characterised by a shrubby grassland. Both the biomes are considered semi-desert environments with an annual rainfall of less than 400 mm. Small stock farming, particularly with sheep (Dorper breeds) and goats (Boer goat and Swakara breeds), remains the primary land use where poverty and high unemployment rates make life extremely challenging in these communal areas. To take advantage of these variable grazing opportunities, herders use either altitudinal transhumance or lateral movements into the adjacent biome.

Samuels (2006) showed that the ages of full-time herders vary between 17 and 71 years of age, and they usually live at stockpost scattered around villages.

A collection of photographs was taken of herders working closely with livestock communities in the Leliefontein and Steinkopf Communal Areas over a decade. Herders gave the necessary consent for the pictures to be taken. Pictures were captured digitally using a Canon 50D and a Canon 77D digital SLR camera. Photographs focused on the herder’s daily tasks and interaction with livestock, dogs and the natural environment.

**Results**

The photo collage in Figure 1 represents the different roles of herders in the study area. A typical herder is illustrated by Fig 1a and shows a slender, built male with protective clothing and a sunhat to protect against the harsh radiation and extreme heat during the summers. They travel light with only the bare minimum, such as a limited supply of water and food to sustain them throughout the day, and a staff (kieirie) to assist in walking and as protection against snakes. Herders are accompanied by one or more landrace dogs, as shown in the image. Full-time herders will normally spend the entire day with the flock guiding them across the landscape to more nutritious fodder (Fig 1b and c). Even though herding in Namaqualand is a male-dominated occupation, one will occasionally find female herders tending to a flock (Fig 1c). Figures 1d and e represent a herder’s role as a midwife during the lambing season. In Fig 1e, the young herder tends to animals for their entire life cycle and keeping an eye on the rest of the flock. Herders assist in walking and as protection against snakes. Herders tend to animals for their entire life cycle and administer medicine to sick animals or provide preventative medication. In the absence of western medication, herders often use indigenous knowledge to concoct their own medicine to administer to animals (Fig 1f). Herders generally have a very good understanding of fodder plants, medicinal plants, and poisonous plants to alter grazing routes to lead animals towards more nutritious fodder plants and medicinal plants or away from poisonous plants. Figure 1g a herder shows a highly palatable fodder plant with some medicinal value. Dogs play a vital role in herding as companionship to the herder and protection for the flock against predators. Figure 1h displays the interaction of a herder with his small-framed dogs and the natural environment.
that are adapted to the harsh environment.

Herders normally live a solitary lifestyle, and whenever there is an opportunity to meet, such as at a water point (Fig 1i), it offers the opportunity to share knowledge and experiences concerning livestock (e.g. sickness, medication), rangeland condition (e.g. fodder plants or poisonous plants location), and the presence of predators.

Figure 1: A collage depiction of the roles of herders: (a) a typical herder with dogs, carrying his staff (kierie), water bottle and food for the day, (b) male herder in the Bushmanland area, (c) female herder in Leliefontein area, (d) herder doing midwife duties in the heat of the day, (e) young herder tending to new-born twin Boergoat kids, (f) herder administering locally made medicine to a goat, (g) a herder sharing his knowledge on fodder plants, (h) a herder and his dogs to protect the flock against predators, and (i) herders sharing local and indigenous knowledge at a water point in the Bushmanland region.

Discussion and Conclusions

The collection of images depicts herders in their daily activities. The photos illustrate that they lead or push animals on planned grazing routes. Understanding plant use and function is an essential part of the job description. Although not formally trained, they seem to have in-depth botanical knowledge and understanding of taxonomy, phytochemistry, nutritional value, toxicity, cultural, and ritual value. Plants are identified through growth form, morphology and colour of leaves and flowers, scent, toxicity, medicinal value, edibility for people, and palatability for livestock (Samuels et al., 2016). Due to the herders’ connection to and understanding of the ecology of the land coupled with ethnobotanical knowledge, they manage to create ‘mental landscape maps’ which are used to direct livestock to more nutritious forages (Samuels et al., 2018). Similar to what Meuret and Provenza (2015) suggest, they developed very specific grazing menus along routes that cater to the animals’ specific needs. Experienced herders have strong botanical knowledge and can identify such fodder plants that livestock need for optimum production. They can also identify poisonous plants and understand how the toxicity in such plants fluctuate seasonally. Therefore, planning such routes becomes more complex after the lambing season. To prevent livestock losses, they have to steer the flock with inexperienced lambs away from such ‘toxic plant patches’ to avoid livestock losses. As livestock managers, they do make use of commercially available medicine or treatment, but if they do not have access to such medicine or if it is too expensive, they revert to traditional medications. Ethnobotanical knowledge, which has been transferred through
generations, concoct treatments. Assisting ewes in the lambing season is the most challenging task and period for herders as they play a key role as midwives to ensure easy birth or assist in complicated births. Tending to goats during this period is particularly challenging as births normally take place on the grazing routes. Since these lambs cannot walk, herders have to carry them back to the stockpost. Preventing livestock losses is key to any herder; therefore, protecting the flock against predators such as jackal, caracal, and leopard is also a high priority. Apart from the companionship role dogs play, their main role is to alert predators’ herder and chase them away from the flock.

We have found that the knowledge required to fulfill the role of the herder is quite complex and can be traced across five broad themes: indigenous, traditional, commercial, scientific, and idiosyncratic (based on individual experience) knowledge systems. The exchange of knowledge between herders normally takes place at the water points. Such gathering places act as informal outdoor classrooms where herding skills, ecological knowledge (e.g. distribution of plants, rangeland condition, weather, location of predators) and even ideas from other media sources are shared. The images in this photo essay illustrate that herding is complex and multifaceted and that it has a complex valuation system that encompasses numerous knowledge systems. Herders provide knowledge and observations that are important for sustainable natural resources management, as shown by Molnar et al. (2020), and these are often overlooked. Given the value herding provide in terms of knowledge creation and their role as knowledge holders, we would recommend herding being considered in future policy direction regarding rangeland management in a variable environment.

Acknowledgements
We would like to acknowledge the herders of the Leliefontein and Steinkopf areas for their willingness to share their local knowledge in this project.

References


Pastoral traditional ecological knowledge dynamicity: a global review

Sharifian Bahraman, A; Fernández-Llamazares, Á; Wario, H; Molnár, Z; Cabeza, M

1 Rangeland and Watershed Management Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran;
2 Organismal and Evolutionary Biology, Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland, Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland;
3 Center for Research and Development in Drylands, Kenya;
4 Centre for Ecology, Hungarian Academy of Sciences, Alkotmány 2–4, 2163 Vácrátót, Hungary

Key words: Indigenous knowledge; pastoralism; transition; transmission; rangelands

Abstract
There is a significant knowledge gap concerning the extent to which pastoral traditional ecological knowledge (TEK) has changed. We conducted a systematic review of 152 papers on pastoral TEK, focusing specifically on 63 papers that explicitly mentioned types of knowledge transitions (retention, erosion, adaptation or hybridization). Studies on pastoral TEK represent less than 3% of all the scholarly literature on TEK. Geographical distribution of the case studies was largely biased. Knowledge domains of pastoral TEK such as herd and livestock management, forage and medicinal plants, and landscape and wildlife were relatively equally covered, however, climate-related knowledge was less studied. Out of the 63 papers explicitly mentioning transition of pastoral TEK, 83% reported erosion, and only 11 studies documented explicitly knowledge retention, adaptation or hybridization. We conclude that future research should focus more on the diverse dynamics of pastoral traditional knowledge, be more careful in distinguishing the four knowledge transition types.

Introduction
After the 1992 Rio Earth Summit, the importance of traditional ecological knowledge (hereinafter TEK) in the conservation of biological and cultural diversity has been increasingly acknowledged by both the scientific community and policy-makers around the globe (Maxted et al., 2002). TEK plays a vital role in the livelihoods of rural communities, and the sustainable management and use of natural resources by Indigenous peoples and local communities (Olsson and Folke 2001). Opinions towards TEK, previously rife with negative characteristics such as being static and archaic, are now appreciating the dynamic nature of this knowledge. There is mounting evidence showing that TEK is adaptive to changes in the environment and it is also fluid with social-economic and cultural changes (Berkes et al., 2000). Despite a myriad of cultural pressures, many aspects of TEK systems are resilient. That is, not all changes in Indigenous and Local Knowledge systems should be understood in terms of knowledge loss, but rather adaptation (Jandrea and Berkes 2016).

In this paper, we aim to synthesize the state-of-the-art of the knowledge on the dynamics of pastoral TEK, cutting across disciplinary topics and regions. To do so, we conducted a systematic review of scientific papers dealing specifically with changes in pastoral TEK. In particular, we addressed whether research is homogenous across knowledge domains (e.g. general ecological knowledge, knowledge on livestock management), and across main pastoral mobility types (i.e., sedentarism, transhumance and nomadism). We focused on four knowledge transition types (i.e., retention, erosion, adaptation and hybridization). Additionally, we documented the main research gaps that highlight the need for a global research agenda on pastoral TEK.

Materials and Methods
The first step of the review process was to undertake a systematic literature search, for peer-reviewed scientific articles about pastoral TEK using Web of Science. We used the following...
Boolean phrase: TS = ("aborigin* knowledge" OR "traditional knowledge" OR "traditional local knowledge" OR "ecological knowledge" OR "traditional environmental knowledge" OR "Indigenous knowledge" OR "local knowledge" OR "folk knowledge") AND (pastoral* OR flock* OR herd* OR shepherd*).

This led to the identification of 382 papers, from which 372 papers were traceable. In the next step of the study, title, abstract and material and method sections of all 372 papers were screened to omit papers unrelated to pastoral TEK. 84 papers were eliminated in this phase. For the remaining 288 papers, we reviewed: types of TEK transition (especially adaptation and hybridization), and the countries where each study was conducted.

In the third step, we proceeded to subsample papers for a more detailed, quantitative review. To do so, the 288 papers were sequentially numbered (1 to 288) and a random number generator was applied (Using the “= RAND ()” function in Microsoft Excel 2019), selecting first ca. 102 papers, with a posterior addition of 50 more papers to assess the robustness of findings. For these papers we collected title, Journal, DOI and First author’s name, and four variables of interest: pastoral system type, studied knowledge domain, mention of TEK transition, type of knowledge transition and robustness of reported transition. Since the relative frequency of the investigated variables was not significantly different between the primary (102 studies) and the final set (152 studies), the remaining (136) papers were not considered in our quantitative analysis. All analyses in this study were conducted in R using Rstudio software [Version 1.2.5033] using ggplot2, dplyr and rworldmap packages. Wilcoxon rank sum test was used to assess the statistical significance of two-level variables (e.g. comparing primary and final database) and Kruskal-Wallis test for observed variables with more than two levels (i.e., pastoral system type) at 95 percent confidence interval.

Results

Pastoral TEK studies are few and geographically biased

The number of scientific studies on TEK in general showed an increasing trend over the last four decades, with a parallel trend for studies on pastoral TEK. However, the proportion of TEK studies focusing on pastoral TEK is low, only 3% of all scientific studies on TEK (Figure 1, A part). Looking at the geographical distribution of research on pastoral TEK (Figure 1, B part), the largely majority of studies were conducted in Africa (50%), followed by Asia (30%) and in Europe (14%). Studies on pastoral TEK were scant in Oceania (3%), South America (2%) and North America (1%). Overall, pastoral communities in 62 countries were studied, with Ethiopia (33 studies), Kenya (31), India (19) and China (18) being the most prominent ones.

Comparing the number of studies conducted on the five major knowledge domains of pastoral TEK, similar attention has been paid to TEK domains related to herd and livestock management knowledge, forage and medicinal plant knowledge and knowledge of landscape and wildlife (i.e., 73, 75, 70 studies, respectively). Interestingly, despite growing research interest on pastoral vulnerability to climate change, pastoral TEK about climate has received relatively scant scholarly attention, with only 15 studies on climate-related knowledge domains.
**Transition in pastoral TEK: erosion vs. retention, adaptation and hybridization**

Transitions in pastoral TEK were addressed in 41% of the 152 papers reviewed in detail (Figure 2, A part). Each of the four types of knowledge transition (i.e., retention, erosion, hybridization and adaptation) was mentioned in at least one paper, with erosion of knowledge being the transition type most often reported (83%). Retention, hybridization and adaptation were mentioned in five, six and six percent of papers, respectively. Out of all the transitions reported, 35% were based on robust empirical evidence, 17% were anecdotal and 48% lied on weak empirical footing, as no traceable form of evidence was provided in the paper. In general, the interest in studying transitions in pastoral TEK is growing in a similar way as the numbers of studies in pastoral TEK (Figure 2, A part). Knowledge erosion was reported in a relatively same frequency for all five major knowledge domains. However, we found a higher relative frequency for domains of Herd/Livestock (42%) and Forage/Medicine (44%) (Figure 2, B part). All domains were reported at least 25% with erosion of pastoral TEK. Without considering retention of TEK as a ‘change’, highest frequency for any type of TEK transition was reported for Forage/Medicine (48%) and Social-cultural (47%) domains. Hybridization and adaptation were reported for only three knowledge domains each. Unfortunately, the small number of available studies makes it difficult to find robust global patterns.

Nomadic, transhumant and sedentary systems with 45% (24 papers), 33% (18 papers) and 22% (12 papers), respectively, were mentioned to be affected by some form of TEK transition (Figure 2, B part). In all three pastoral system types erosion was the most often reported transition, and in most cases retention, adaption and hybridization was found only in a few cases. Further research is called upon to obtain better and more representative understanding the differences in knowledge transitions across different pastoral mobility systems.

**Figure 2:** A part: Frequency of papers meeting review criteria by year considering TEK transition. Inserts: C) relative frequency of papers reporting TEK transition; D) relative frequency of papers reporting different types of transition. B part: Types of TEK transition reported for each major knowledge domain. B: TEK transition reported for different pastoral mobility types (Black labels show percentage values, while red labels the total number of papers)

TEK erosion was commonplace globally, but most often reported in Asia and East Africa (Figure 3). Europe, Asia and Africa had 55, 53 and 31% of their total number of studies, respectively, reporting some form of TEK transition. Reported transition showed Ethiopia, India, China, Kenya, Egypt and Spain with more reports of erosion. Although comparing the status of TEK transition between countries is difficult to the fact that research effort is far from being homogenous across countries, it is important to highlight that TEK erosion is reported in most of the studied countries, even in biologically and culturally diverse regions.
Discussion

Low number of studies on pastoral TEK provides further support to calls by Fernandez-Gimenez (2000) and Molnar (2014) to bring more into focus pastoral TEK. In line with our results, the UN Environment report on number of studies on rangeland and pastoralism confirms that compared to other topics, research on rangelands and pastoralism is substantially lower (96,414 records from 71 million records), and that pastoral TEK studies cover only one percent of total studies and projects on rangeland and pastoralism (Johnsen et al., 2019). The relatively higher number of papers reporting pastoral TEK erosion may be alarming for local, national and international organizations aiming to promote sustainable use of rangelands and biocultural conservation of pastoral social-ecological landscapes. Aswani et al., (2018) and Hanazaki et al., (2013) have reported the same result with conducting reviews on TEK transition amongst other communities such as farmers, hunter-gatherers, fishers and found that 77% and 57% of the papers reported TEK erosion. Another research gap in pastoral TEK studies was that although different transitional types have been reported for pastoral TEK, most of the studies have called TEK transition as erosion. As it was also emphasized by Tian (2017), TEK transition is mostly evaluated linearly as gain or loss, however, adaptation and hybridization of TEK are also possible – and highly relevant - changes. Researchers have often assessed the transition of pastoral TEK by comparing the volume of the knowledge between or within generations (Oteros-Rozas et al., 2013) and referred to lower volume of knowledge of the younger generation as erosion. We argue that erosion of TEK concerning specific subdomains should not automatically imply the overall downward trend of communities’ TEK. In fact, this change may originate from adaptive strategies and/or hybridization of knowledge due to exposure to other knowledge systems.

Constant long-term presence and monitoring by pastoralists of their social-ecological systems have enabled them to develop rich bodies of knowledge and practices about their local ecologies. Understanding this knowledge is pivotal for sustainable management and nature conservation. Yet, our result showed that studies on pastoral TEK cover only three percent of total studies on TEK. Despite the fact that pastoralists carry knowledge in several domains, our attention has been more fascinated by their knowledge regarding Herd/Livestock, Forage/Medicine and Landscape/Wildlife, leaving their perception from Climate and Socio-cultural less represented. How international planning and management for rangeland and pastoralism is possible while our knowledge pertaining pastoral TEK covers spatial scale of their distribution, insufficiently. Notwithstanding this amount of studies on pastoral TEK, our review showed that knowledge erosion may be the dominant type of knowledge transition occurring among pastoralists worldwide. However, knowledge adaptation and hybridization proved to provide solutions to new challenges in many areas of the world, despite the fact that they continue to be under-researched. We argue that stronger research focus is needed on the transition of pastoral TEK to help the ongoing adaptation of pastoral systems including changes in their TEK among ongoing global changes. Scientific research should cast more light on different transition types. Furthermore, parallel to different changes such as land use-rights and economy of pastoralists, changes of pastoral TEK should be taken into consideration as one of the pivotal changes faced by pastoral communities around the world. Finally, documentation of
pastoral TEK should continue as different changes in its transition from one generation to another may lead to new forms of knowledge about livestock, plants, soil and human interactions.

References


Transdisciplinary research in practice: lessons from participatory, folklore and community-supported approaches in the greater American West

Wilmer, H.; Carr Childers, L.; Porensky, L.M.

1USDA-Forest Service Pacific Northwest Research Station/Northwest Climate Hub, Juneau, AK, USA; 2Department of History, Colorado State University, Fort Collins, CO, USA; 3USDA-Agricultural Research Service Rangeland Resources and Systems Research Unit, Fort Collins, Co. USA

Key words: oral history, ranchers, collaborative adaptive management

Abstract

Rapid social and ecological changes on global rangelands amplify the challenges to achieving biodiversity conservation, rural economic viability and social well-being, and rangeland sustainability. These dynamics create a need for transdisciplinary science inclusive of ecological, sociological, and participatory approaches to rebuilding meaningful working relationships between scientists, ranchers and managers, and other rangeland stakeholders. In a real application, however, transdisciplinary science faces numerous social, ethical, and logistical challenges, including the question of how the work might benefit rangeland stakeholders. Our objective is to advance rangeland researchers’ toolbox for meaningful, engaged research by describing three lessons from transdisciplinary projects in the rangeland contexts of the United States. These include the need for 1) ranch-scale, long-term participatory management experiments, 2) folklore and oral history methods, and 3) community-supported social-ecological research that creates credible science that can be communicated to non-ranching decision-makers. These examples illustrate the nuances of transdisciplinary research, reciprocity, and useable knowledge creation in complex rangeland social-ecological contexts.

Introduction

Producing food that sustains biodiversity and quality of life is a complex challenge that requires tools for transdisciplinary knowledge development and exchange. Rangeland-based livestock (largely cow-calf, yearling, sheep, and bison) production systems in the US West have the potential to help sustain biodiversity while supporting rural communities and food systems across the region. However, managers here are challenged by multiple interacting drivers of change stemming from climatic, ecological, social, and economic systems. Rangeland scientists and managers increasingly recognize the value of transdisciplinary collaborations, inclusive of ecological, sociological and local knowledges, to successful solution-oriented science. Such efforts depend upon methods that effectively engage and value our partners’ knowledge and management contexts. This paper expands working land researchers’ toolbox for meaningful, engaged research by describing lessons from three approaches (Table 1): 1) ranch-scale, long-term participatory management experiments; 2) folklore and oral history methods; and 3) community-supported social-ecological research. These approaches represent tools that encompass or can be used within larger transdisciplinary projects. Drawing from our experiences, we summarize these approaches’ potential applications, benefits, and limitations to inform future projects and partnerships across rangelands and agroecosystems generally.

Three tools for transdisciplinary engagement in rangelands

Ranch-scale, long-term participatory rangeland management experiments

Our first approach is participatory research conducted at large spatial and long temporal scales. On the semi-arid shortgrass steppe ecosystem of eastern Colorado, USA, the USDA-Agricultural Research Service (ARS) Central Plains Experimental Range (CPER) is a ~6,000 ha research station that has traditionally produced research to inform ranch, conservation, and USDA-Forest Service managers, especially on the nearby Pawnee National Grassland. Here, a ten-year ranch scale (2,600 ha) participatory grazing
experiment brings researchers and agriculture producers, conservation interests, public agency professionals, and outreach experts to advance our knowledge of trade-offs and synergies among beef profitability, drought resilience, biodiversity, and social learning objectives. The Collaborative Adaptive Rangeland Management (CARM) experiment tests the hypothesis that a collaborative team can use experimental data together with local and professional knowledge to manage a herd of yearlings on 10, 130 ha paddocks for multifunctional outcomes more effectively than those realized by a second herd of (the same number) yearlings grazing 10 ecologically paired paddocks in a system similar to the local “business as usual” season-long, continuous grazing system (Wilmer et al., 2018). Cattle graze during the growing season (mid-May through October), and participants decide the project objectives, cattle stocking rates and grazing systems, and use of prescribed fire. As part of a larger-scale network of research sites in the USDA-ARS Long-Term Agroecological Research (LTAR) network, CARM management practices and outcomes are monitored extensively at multiple scales by an interdisciplinary group of rangelands, animal science, social science, hydrology, modelling, and economics researchers.

While results of the first eight have been reported elsewhere (Augustine et al., 2020), the “CARM team” has recognized key qualities of the project that enhance the effectiveness of the collaboration. First, the project occurs in the local ecosystem near and in partnership with working ranches and land managers. This enables immediate relevance to private and public land managers. Second, unlike many pilot-scale experiments, CARM operates at the ranch scale, thus better reflecting real-life management’s decision-making context. Critically, the project includes a ranch-scale control (“business as usual”) treatment, which enhances analytic power and enables the team to interpret treatment and weather effects. The decade-long time frame enables sufficient time for treatment effects, learning, relationships, and variable weather patterns to emerge. The timeframe also demonstrates a commitment to partner groups and individual participants. Limitations of this approach include the logistical complexities, expense, time commitment and complexity, which require additional interdisciplinary collaboration.

| Table 1: Three tools to enhance transdisciplinary approaches in ranching and rangeland-based contexts. |
|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| **Case location or ecosystem** | **Oral history** | **Community-based social-ecological research** |
| Ranch-scale, long-term experiments | Western US rangeland-based communities (Carr Childers, 2013) | Ecotone between mixed-grass prairie and sagebrush steppe |
| Sustainable ranch management for multifunctional goals | Ranching community vitality, knowledge transfer, and public perceptions of rural peoples | Resilience to weather/climate, conservation, social, economic challenges |
| Experiments conducted at spatial and temporal scales relevant to real-life management; control treatments enhance analytical power | Format honors rural cultures and traditions, documents individual history and place-based ecological knowledge | Collaborative research question identification, cross-checking, outward-facing science, and quantification |
| Requires time and funding commitments, and access to large experimental stations or ranches may be needed. | Digital, travel and transcription funds needed. Historians can collaborate with local museums. | Community trust, consent, and participation require ongoing negotiation. Build in reciprocity. |
| Pairs well with Long-term experimental projects, University Extension efforts, network-scale science | Science synthesis and digital outreach programs | Efforts to manage across multiple land tenures and/or worldviews (e.g. management of public lands grazed by private ranchers) |
Folklore and oral history methods

In ranching and rural communities, oral storytelling is an important form of cultural reproduction, meaning-making, and identity formation. A second tool, oral history, engages the humanities in a novel approach to respecting and integrating local managers’ experiences on the land and ecological and business knowledge into the broader body of knowledge informing rural community and rangeland sustainability. A model for this approach is found in the Nevada Test Site Oral History Project at the University of Nevada, Las Vegas. Between 2003 and 2008, historians collected the oral histories of those involved with and affected by the nation’s nuclear testing program. Simply put, «oral history collects memories and personal commentaries of historical significance through recorded interviews» (Ritchie, 2015). Oral history can be used in communication and collaboration with rangeland science synthesis, co-production, or ranch-based projects to improve communication, learning, and place-making.

Funded by the US Department of Energy, the project initially captured the institutional knowledge of how nuclear testing evolved between 1945 and 1992. However, project director Mary Palevsky expanded its scope to include those living in the test sites rural areas, particularly ranchers. Though located on the geographic and intellectual periphery of the project, these interviewees became central to understanding the changes nuclear testing wrought on the land and in the lives of those living in proximity to the test site. They also demonstrated how science and safety communication about nuclear testing was predicated on the creation of relationships with radiation monitors sent to these areas (Carr Childers, 2013). The shared authority model inherent in oral history production creates buy-in from community members by elevating the work of non-scholars. In the participatory framework of shared authority, oral historians work with narrators to produce interviews rather than produce them for the narrators’ communities (Frisch, 1990). The difference between producing with and producing for is giving and taking.

In recent years rangeland science has increasingly recognized the inextricable links between social and ecological processes (Hruska et al., 2017). Oral histories help round out the past stories by augmenting documentary and photographic records with unwritten recollections. They also reveal how individuals and communities have experienced the forces of history, particularly in the case of the less formally educated and less powerful, and how the past links to the present. However, it is important to remember that oral history interviews reflect individual perspectives, are predicated on the conversation between the interviewer and the interviewee and are grounded at the moment in which they are collected. For oral history interviews conducted with rancher narrators, it is critical to include those whose multi-generational ranching families have operated on the land over a long period of time to garner the depth of knowledge and connection they have to ecosystems and landscapes.

Community-supported social-ecological research

Our third example comes from the Thunder Basin Ecoregion of northeastern Wyoming, an ecotone, or ecological boundary zone, between the Great Plains’ grasslands and the Intermountain West’s shrublands. Various interest groups pursue ranching, conservation, energy development, and other land use goals here. For example, the Thunder Basin Grasslands Prairie Ecosystem Association (TBGPEA), a landowner-led non-profit organization, has worked for 20 years to “Develop a responsible, common sense, science-based approach to landscape management within the five northeast Wyoming counties.” Under this mission, TBGPEA collaborates with researchers to solve ecology, climate, grazing, wildlife conservation, economics, and social science problems.

The collaborative effort uses several key methods. The first is co-design. TBGPEA collaborates with researchers and other partners to identify research questions and approaches. Transforming real-world problems into research projects is difficult, and substantial front-end effort is needed to ensure that the research project results will feedback into relevant results that help solve the problem on the ground. Second, we use cross-checking or regular interaction among partners. This ensures research results can be continually evaluated against local knowledge of the social-ecological system. When results don’t match up, a key approach is to give equal weight to scientific and local knowledge. This leads to fruitful discussions around why discrepancies might exist and what additional information might be needed to resolve or explain differing findings (multiple truths, Cote and Nightingale, 2012). This approach contrasts with a typical manager-scientist dynamic in which each group regularly assumes that their understanding of the system is “more correct”. Sometimes, discrepancies cannot be resolved. However, these discussions lead to additional investigations or analyses that produce a deeper or more complete understanding of the system.
Third, we enhance the benefit to the community by producing outward-facing science that communicates local knowledge to the outside world in a credible, objective format. As stated above, research results do not always match up perfectly with local knowledge. However, research winds up saying with scientific confidence what many people already knew to be true in many cases. In these cases, research can help the community by creating peer-reviewed, scientifically acceptable literature that supports local understanding of how things work. Fourth, science can help solve problems by quantifying trade-offs or synergies within the system (Duchardt et al., 2019). For example, science can help people move from statements such as “prairie dogs reduce livestock weight gains” to “prairie dogs reduce livestock weight gains by X%, corresponding to a reduction of ranch revenues by $Y”. The latter statement opens up avenues for action (e.g., payment for ecosystem services) that are not available without quantification of the problem. Quantification can benefit the local community and reduce conflict by clarifying the costs and benefits of different approaches. Community-supported social-ecological research hinges on researchers’ ability to prioritize community relevance over scientific impact. Managers, in turn, can expect to sacrifice some real-world complexity due to the constraints of research study design. All partners benefit from recognizing that scientific findings will not always support the community’s worldview, preferred management style, or policy agenda. All partners need to go into the work with the clear-eyed recognition that results are unknown, and research is held to high ethical standards.

Discussion

Rangeland-based food systems are unique places where many land users, forms of biodiversity, and complexity interact. It is thus appropriate that rangeland researchers and stewards seek creative and boundary-spanning methods for engagement, knowledge production, and social learning. Above, we describe specific approaches to conducting scholarship with communities to offer researchers, ranchers, and other practitioners tools to advance transdisciplinary solutions to sustainability problems, better understand one another and respond to real management contexts. There are several limitations of the tools, including that they may be more time, resource, and emotionally demanding than conventional ecological or grazing research. Additionally, they require additional thinking about ethics, risks to participants, and benefits to communities. However, our experiences suggest that key aspects of the tools are beneficial, including engaging deeply with communities and practitioners with cultural competency and in forms and spatial and timescales that matter to specific historical, cultural, and place-based contexts. As researchers increasingly recognize the importance of engaging practitioners and communities in our work, it is also important that we integrate a methodological consideration of culture, place, and process in our methods.

Acknowledgements

We thank Dave Pellatz from the Thunder Basin Prairie Grassland Ecosystem Association in Bill, WY, USA.

References


Shift in management strategy of yak herding in the south of Mustang District, Nepal, Himalaya

Anzai, H¹; Shah, M.K²; Kumagai, H³.

¹ Faculty of Agriculture, University of Miyazaki; ² Nepal Agricultural Research Council; ³ Graduate School of Agriculture, Kyoto University

Key words: Himalayan mountain range; transhumant pastoralism; Yak

Abstract
In the Himalayan regions of Nepal, people herd yaks (Bos grunniens) under transhumant pastoralism, seasonal migrations of herds between summer highlands and winter lowlands. For several decades, the number of yaks has decreased, and the management strategy of yak herding has been altered due to the influence of substantial changes in both the social environment and their livelihoods. We conducted field surveys on yak herding in the south of Mustang District from 2012 to 2016 to examine the recent shift in management strategy and practice. The surveys were focused on fifteen yak owners and their herdsmen who lived in southernmost three villages in the district and organized a yak owners’ cooperative group. The herd scale has been constant in recent years, although the owners had a willingness to increase the scale. The herding practices were traditional and extensive, which might not have led to an increase in herd size or productivity. Dairy production has shown an obvious declining trend, whereas sales of meat and the revenue from the yak blood drinking festival hosted by the cooperative group have become more important income sources for local yak herding in association with the development of local infrastructures and livelihoods. Because the economic incentives for yak herding remained strong in the study area, the herding scale will be maintained, or expanded if the management practices are improved in the future.

Introduction
Yaks are the most indispensable livestock for people living in Asian inland highlands. Yaks are kept for various purposes, including milk and dairy products, meat, wool, hides, feces (as manure and fuel), draft power and pack animals. In the alpine and sub-alpine regions in Nepal, Himalaya, people rear yaks under transhumant pastoralism, seasonal migrations of herds between summer highlands and winter lowlands. Nepal has a population of 70,000 yaks and its hybrids with cattle in 2011, decreased from an estimated 200,000 heads in 1961, partly due to government restrictions on livestock numbers and access in national parks (Wiener et al., 2003). The attractions of the tourist business for increasing trekkers and other economic options have also reduced the incentive to pursue yak herding (Joshi 2000). In addition, the production strategy of yak herding has been altered over the last several decades in Nepal (Bishop 1989).

Mustang District had a population of 12,318 people and 3,215 yaks in 2010 (Mustang District Development Committee 2011). Almost half of the yaks are kept in Kali Gandaki Gorge, the south part of the district. The southern area of the district, called Thak Khola, is the home province of the ethnic group of Thakali (Vinding 1988). Manzardo (1984) and Degen et al., (2007) conducted field surveys in this region and reported on their yak herding. In recent years, the livelihoods in Mustang District have been drastically changed by infrastructure development, such as the distribution of electric power network, the conversion of fire source from fuel wood to gas cylinders, and the rapid spread of mobile phones. In particular, the improvement of Jomsom Street as an arterial roadway for vehicles has substantially activated flows of people and goods. The local yak herding may have been affected by these changes. We conducted field surveys on yak herding in the south of Mustang District to examine its recent shift in production strategy and management practice.

Materials and Methods
The investigation was conducted in the southern parts of Mustang District (28.7°N, 83.6°E). The study site is located in the steep gorge between Mt. Dhauragiri in the west and Mt. Nilgiri in the
east. At the bottom of the gorge, the Kali Gandaki River flows from north to south, and Jomsom Street runs along the river. The street has been an important route for the salt trade from Tibet and for the pilgrimage to Muktinath Temple, a sanctuary for Hindus and Buddhists. The area has been a part of the Annapurna Conservation Area and recently popular for foreign trekkers. Since 2008, the street has been completely open to traffic for vehicles from Beni, the headquarters of Myagdi District, to Jomsom, the headquarters of Mustang District. Although the street was often divided by summer heavy rains and landslides, flows of people and goods have increased.

We visited the site and conducted surveys eight times: Dec. 2012, Apr. 2013-2016 and Sep. 2013-2015, each for a month. Fifteen yak owners who lived in Kowang, Lete and Kunjo VDCs (village development committees) organized and belonged to a yak owners’ cooperative group. We interviewed these yak owners and herdsmen employed regarding their management and production practices of yak herding.

Results

Yak herding

Among the 15 yak owners, three had kept yaks for more than 50 years, but three owners begun herding during this decade. Eight and five owners employed one herdsman (called gothalo) with a one-year contract each in 2014 and 2015, respectively, and one owner employed two herdsmen in both years. The other owners cared for their herds by themselves. On average, NRs. (Nepalese rupee) 70,000 and 76,000 were paid per year per herdsman in 2014 and 2015, respectively, with a provision for clothing, food, tent and daily necessities. The average herd size was 51 heads, ranging from 33 to 149. Breeding females at the age of 3 years and above accounted for 67% of the total, whereas most males were slaughtered around the ages of 3-4 years, except for one or two head(s) of sire in a herd. Although the owners were willing to increase their herd size, accidents such as a snow slide in 2009 and an epidemic of foot-and-mouth disease in 2013 killed many yaks at once. In April 2015, there were totally 514 breeding females in the 15 herds. For two years from April 2014 to March 2016, 498 calves were delivered, whereas 236 calves died within a year after birth. The major causes of death were attacks by wild animals such as snow leopards (Uncia uncia), ingestion of poisonous plants and slip drops from cliffs. When a calf dies, milking from its dam would be difficult until the next calving.

Yaks were kept by year-round transhumant pastoralism on pastures at the bases of mountains. They grazed on grasslands and forests ranging between 2,500 m and 3,400 m asl from November to April (winter) and on grasslands between 3,400 to 4,600 m asl from May to October (summer). Only salt was fed to yaks once a week in summer and twice a month in winter. Eight of the 15 owners stayed in the tents almost every night during the busy period to care for the calves and pump milk (generally May to August), while the other 7 owners did not continuously stay in tents. During winter, the herds constantly migrated from one pasture to another when there was little grass. Because the winter pastures were closer to their settlements and herding was less busy, herdsmen less frequently stayed in tents.

Dairy production

After calving and migration to summer pastures, herdsmen began to milk. They pumped 1-1.5 L of milk per animal per day only in the morning. Ghee (clarified butter) and hard cheese (chhurpi) were made from acidified milk. A kilogram of ghee was made from 22-26 L of milk in summer or 17 L in winter and sold for NRs. 667. A kilogram of chhurpi was made from 17 L of milk and sold for NRs. 275. The milking duration varies by herd; five herds were milked every day for 4-6 months, four herds were milked every day for 1-3 months, and six herds were not continuously milked. The average annual sales for dairy products in 2014 and 2015 were NRs. 15,053 and 6,447 per herd, respectively, ranging from NRs. 0 (no sales) to 41,000. Eight of the 12 owners who had conducted yak herding for more than a decade responded that the milking duration had decreased compared with a decade ago, whereas three owners answered ‘not different’ and one owner answered ‘increased’.

Sale of meat

Young male yaks not for sire, old sires, and female yaks which were old or had some reproductive difficulties were slaughtered for meat. Female yaks were mostly culled at the ages of 9 to 14 years. Leans with bones and edible internal organs were divided into even portions of 2-3 kg and sold for NRs. 2,000 each. A head and four limbs were totally sold for NRs. 2,000 as food; a tail was sold for NRs. 1,000-3,000 as a traditional ornament or as a souvenir; and a gall bladder was sold for NRs. 500-1,000 as a crude drug. Fur skin or wool was domestically used as a carpet or thrown away. A 3-year-old male, a 10-year-old male and a 10-year-old female were sold for approximately NRs. 34,000, 80,000 and 60,000, respectively. From April 2014 to March 2016, 47 young males, 6 old males and 52 females in the 15 herds were slaughtered; in total, 105 yaks were sold for NRs. 5.6 million. The average annual sales per herd in 2014 and 2015 were NRs. 273,200 and 96,533,
respectively, ranging from NRs. 0 (no sales) to 498,000.

Blood drinking festival

The owners held traditional festivals on pastures in April-May (Baisakh on the Nepalese calendar) and in July-August (Shrawan). The spring festival was held only by the surveyed group at a place along Jomsom Street, whereas the summer one was also held by other yak owners around the area, at every herder’s tent on summer pastures. During the festival, they cut the jugular veins of the yaks with a blade and poured the blood into cups of around 200 ml. People drank the blood because they believed that drinking yak blood might cure their gastric problems or diseases as a crude drug but not owing to a religious belief. Blood was collected from most male and unpregnant female yaks aged 2 years or above, and 10-15 cups of blood were obtained from each animal. A cup of blood was sold for NRs. 150 in 2013-2015 and for NRs. 200 in 2016. The festival continued for around 10 days until the participants were sated with drinking blood. The owners, their family members and some participants stayed in tents on pasture during the festival, and the owners’ families earned money by providing beds, food and drink. Although this festival was one of the traditional and seasonal festivals for Thakali, people including non-Thakali visited from distant places. In April-May 2015, around 2,500 cups of blood were sold. Five yaks were slaughtered for meat during the festival after blood collection.

Recent trends in the price and sales of yak products

The sales from dairy products and the proportion out of the total sales particularly decreased from 2005-2007, as reported by Degen et al., (2007), to 2014-2015, as obtained from our interview surveys (Figure 1). The sales from meat and blood almost doubled, which corresponded to the price increase rates of meat and blood. The total annual sales of yak products per herd increased by 72% from NRs. 130,195 in 2005-2007 to NRs. 224,783 in 2014-2015, mainly owing to the price increase in yak meat products.

Discussion

Approximately one thousand heads of yak were herded by 29 owners in Kowang VDC in 1977 (Manzardo 1984). Although the number of yaks and herds has decreased, the decrease rate was rather smaller than the national trend of Nepal. The mean herd size (51 heads in our survey) has been increasing since 1977 (34 heads) and has remained constant since 2005-2007 (51 heads; Degen et al., 2007). The fact that three owners began yak herding in this decade indicates that yak herding has been still attractive to some people in the area. Although the owners were willing to increase their herd size, several external factors (e.g., wildlife attacks, snow slides and epidemic diseases) prevented it. Management practices of herding were traditional and extensive. The grazing system without supplemental feeds caused low health and mineral nutrition statuses, especially in winter (Kumagai et al., 2016), and reproductive disorders (Aryal and Paudel 2007). Appropriate feed supplementation can reduce these problems and may increase herd size and productivity.

In most cases in Nepal, dairy production has been referred to as the primary purpose of yak herding (Wiener et al., 2003). In this area also, yaks were utilized for dairy products and the production of several types of wool in the 1980s (Manzardo 1984). However, dairy production showed a
declining trend, although the milking capacity of dams was far greater than the actual milking amount for most of the herds. Assuming that all of the lactating dams were milked 1 L for 4 months after calving and all of the milk was processed into ghee and chhurpi, NRs. 44,000 could be gained per herd per year. Several owners explained that they reduced the milking amount or duration to let the calves drink more milk and thereby improve calf mortality. However, the declining trend might also be attributed to following factors. Although the production amounts of yak dairy products decreased, the price increase was similar with that of milk at the national level, which indicates a decreasing demand for yak dairy products in the study area. This decreasing demand might be related to the increasing availability of fresh or powdered milk for the local people in association with the development of transportation via Jomsom Street. The local people every day took tea with these kinds of milk but did not routinely take ghee or chhurpi made from yak milk. Moreover, because milking and dairy processing requires great daily labour, several owners might think that dairy production does not pay for the work.

In Nepal, contrary to dairy production, the production or consumption of yak meat has been less frequently referred to, which might be partly because the slaughtering of yak and consumption of its meat conflict with religious issues due to the closeness of yak to cattle. The consumption of yak meat had been temporarily regulated in this area in the course of Hinduization (Manzardo 1984). However, the regulation has been eliminated, and the local people preferred to eat yak meat. The sales for meat were the most important income source for the local yak herding. The relatively high rate of the price increase in yak meat might be attributed to the increasing demand. Since the sale of meat was held irregularly, the spread of mobile phones and the expansion of transportation have offered an opportunity for more people to purchase the meat.

The revenue obtained from the blood drinking festival including the sales of blood was also an important income source for the local yak herding. In the 1980s, the spring festival was held in May-June (Jestha) at a one-hour walk pasture from Jomsom Street and was traditionally less important than the summer festival for Thakali (Manzardo 1985). The season of the spring festival has been changed to April-May because many people can visit the festival during this time, which corresponds to the New Year holidays of Nepal. The location has been changed to a place along the street since 2009, associated with the opening of the street for vehicles. Owing to an increase in accessibility to the place, the spring festival has expanded in scale and become economically more important than the summer one for the surveyed group. As well as transporting trekkers’ baggage or value-added cheese production at other places in Nepal (Wiener et al., 2003), the festival has given an opportunity to utilize yaks for tourist business. This unique and successful utilization of yaks might be attributed to a high level of business skills of Thakali (Kawakita 1955). However, the scale expansion of the festival may increase the risk of losing animal health because 2 to 3 L of blood are collected from an animal after the severe winter season.

The production strategy of yak herding in the study area has been altered in association with the development of local infrastructures and livelihoods, whereas the scale of yak herding and basic management practice have been maintained in recent years. Although options for local people to make a living might have been expanded, the incentive for yak herding seemed to remain strong. The economic incentive particularly derived from the sales of meat and the revenues from the festival. Owing to the high incentive, the scale of yak herding will be maintained, or if the management practices are improved, will be expanded in the future.

Acknowledgements
This study was supported by a Grant-in-Aid for Scientific Research (B) (Grant number: 24405041) from the Japan Society for the Promotion of Science. The authors are grateful to the local yak owners and herdsmen who cooperated with our surveys.

References


Mustang District Development Committee, 2011. *Livestock census of Mustang District 2067/068*. (in Nepalese)


Women and their children in charge of management decisions of a communal range

Trejo-Arista, L. K.1; Martínez-Hernández, P. A.1; Cortés-Díaz, E.1

1Posgrado en Producción Animal, Universidad Autónoma Chapingo, Chapingo, México.

Key words: participatory workshops, management plan, extensive livestock production.

Abstract
In many rural Mexican areas women take care of family’s farm and agricultural lands due to the emigration of men. Tepetixtla, a community in the Mexican state of Guerrero underwent such situation, thirty-five women with their children oversaw a communal range of 300 ha and 90 head of cattle. From these resources they are expected to provide food and shelter for their families. At the same time, they were concerned about environmental issues as their range was in poor condition, mainly having areas without vegetation and increased presence of plant species cattle do not graze. The objective of the study was to develop a series of hands-on and participative workshops along with short films on environmental issues in which the women and their children (4 to 10 years old) participated. The results of such activities were that the women were convinced that maintaining or improving livestock production from their range should go hand-in-hand with environmental gains too. Following their cattle, they identified browse species, *Leucaena leucocephala* and *Guazuma ulmifolia*, among others, collected their seeds, developed a nursery for the initial growth of such species and started a reforestation plan. Protection of wetlands from livestock and restoration of gullies were also within their near-future plans. It was concluded that men’s emigration from rural areas is a challenge for women and their children as they need to take care of farms and agricultural lands; however, with proper training women and their children can tackle successfully such challenges.

Introduction
Mexican extensive livestock farming in tropical communal ranges faces multiple challenges: to be a source of enough income to pay for food, shelter, and medical care of family members, to be environment-friendly to preserve natural resources for future generations, and to be an activity that keeps young people away from migration to cities and elsewhere (INIFAP, 2011). Actual soil and vegetation degradation of tropical ranges increases the magnitude of the challenges mentioned (Ibarra *et al.*, 2018). Men, traditionally the head of the family, migrate as they do not find a solution to these challenges, leaving behind the management of livestock and land to their wives and children. State extension personnel are not trained to work along with these rather new and poorly experienced livestock and land managers.

New and pertinent extension programs need to be brought to the field to meet all these conditions at the same time. The objective of the study was to validate a series of hands-on and participative workshops along with short films on environmental issues to enable women and their children (4 to 10 years old) to successfully address the management of land and livestock.

Methods and Study Site
The study was carried out from January to December 2015 in the community of Tepetixtla, Coyuca de Benítez, Guerrero, Mexico, which has a warm (25.9°C annual mean temperature) sub-humid (annual rainfall of 1,141.5 mm) climate. The vegetation is sub-deciduous forest (SMN, 2010). Thirty-five women, who were in charge of a communal range of 300 ha and 90 head of cattle, participated with their children. Four participatory workshops (Geilfus, 2000), a field trip to share experiences with similar groups and short films were the core of the extension strategy applied. At all times open discussion and questioning was encouraged. The leader and main person in charge of the whole extension strategy was a woman.

The themes developed and shared with all members of the group (women and children) were:
Estimation of forage and browse mass in the range: procedures and importance in livestock feeding.

Stocking rate: estimation and changes year-long.

Identification of forage and browse species in their own range and ranges within the region.

Propagation and initial care (nursery) of forage and browse species adapted or native to the range.

Strategic use of the range: rotation of grazing areas, range rehabilitation procedures.

Results

Estimation of forage and browse

This workshop was carried out during a field trip in which the attendees were exposed to the importance of knowing the mass of forage available in the rangeland. The first three samplings in each of the transects were carried out by the instructors, but later it was the residents who continued sampling the vegetation to complete 10 points per transect. The results of the sampling of both transects were as follows. For Transect 1 (north to south), an amount of 5320 kg DM/ha was estimated for the herbaceous component with an $R^2$ of 0.977, while for the arboreal component a total of 131.06 kg DM/ha, which amounted to a total of 5451.06 kg DM/ha. In Transect 2 (east to west), an amount of 4980 kg DM/ha was estimated for the herbaceous component with an $R^2$ of 0.989, while for the arboreal component a total of 90.55 kg DM/ha was estimated, which added a total of 5070.55 kg DM/ha. With the data from these samplings, the differences between one transect and another were discussed with the attendees, and although the difference in forage mass between them was little, most had identified which had less even before the aforementioned quantities had been calculated. Once the doubts about how to calculate the forage mass were resolved, a list was made with the weight of the animals that the OCSS participants had, which is the total number of animals that are grazing in the 300 ha in which the sampling was carried out. A total of 90 animal units were obtained. These data were stored to later offer the workshop an adjustment of animal load.

Stocking rate

With the data from the forage mass sampling, in the workshop the importance of managing an adequate stocking rate to allow rangeland improvement was discussed. It was estimated that 13.5 kg DM of forage are needed to maintain an animal unit for 1 day; that is to say that to maintain 90 animal units for a year, 443,475 kg DM are needed. According to the mass of forage obtained in the two transects, the average was 5260.8 kg of DM/ha in the rangeland, so at the time the sampling was carried out there was enough forage for the maintenance of all the cattle. Several exercises were carried out with the assistants to emphasize the variations in forage accumulation that occur during different times of the year and how they should be aware of these variations in order to carry out sampling and stocking adjustments.

Identification of forage and browse species

In the field, browse species most preferred by cattle were identified, and the five tree species with browse potential were: leucaena (Leucaena leucocephala), cubata (Acacia cochliacantha Humb. & Bonpl), guácima (Guazuma ulmifolia Lam.), huizache (Acacia farnesiana) and guamúchil (Pithecellobium dulce). Afterwards, the literature review was carried out to discuss with the attendees about the characteristics of these species and to define a seed collection calendar. Areas affected by overgrazing were identified, which is why reforestation with these species in degraded areas was also discussed as a strategy to improve the rangeland. In the workshop on the use of supplementary forages, the need to establish a nursery was identified. The community defined that only leucaena (Leucaena leucocephala) and guácima (Guazuma ulmifolia Lam.), seed would be collected, which are the preferred trees for cattle and were the next to have seed at that time. Seven (7) kg of leucaena seed were collected and 5.6 kg of guácima, the seed was stored properly. At the end of the tour, a short film on environmental education for children was screened. At the end of this activity, the opportunity areas that participants identified in their community were discussed along with strategies for the restoration and conservation of their natural resources that could be used. In general they agreed that the degraded areas of the rangeland were those that most required attention.

Propagation and initial care of forage and browse species

In this workshop, the use of supplementary forages as a strategy to improve the rangeland was presented, as well as the main characteristics of the species proposed by the project, such as their nutritional value and the considerations to take into account in their establishment. At the end, a leucaena (Leucaena leucocephala) and guácima (Guazuma ulmifolia Lam.) nursery was
established, 1500 seedlings of each species were planted, and a reforestation plan was drawn up, in which the areas with the highest degree of degradation identified in the tour were prioritized.

**Strategic use of rangeland**

The rangeland management plan was defined with the participants of the different workshops, the appropriate dates were set to estimate the available forage to adjust the animal load. Likewise, the reforestation plan was included, and the zones were prioritized. Finally, as goals for the near future, strategies were proposed for the restoration of gullies through reforestation and the protection of wetlands against livestock through natural barriers.

**Discussion and Conclusions**

Being able to work with women and their children in Tepetixtla to generate strategies that are focused on the conscious management of the rangeland and grazing was fundamental to direct the extensive cattle ranching of the region towards sustainability (Zabalza et al., 2017; Pateiro et al., 2020). The workshops on estimating available forage and adjusting animal load were a key element in promoting this sustainability, since one of the factors that most limit the productivity of livestock farms is the inadequate management of grazing, since in most cases it uses an animal load greater than the support capacity of the rangeland (Briske et al., 2008). Among the disadvantages of managing a high animal load in the rangeland are the reduction of the basal cover and the diversity of forage species, which affects forage production, as well as the destruction of habitat of wild fauna or loss of its quality, which causes damage to populations of both animal and plant species (Chávez and González, 2008; Ibarra et al., 2018).

In addition, the use of a sustainable animal load in the rangeland allows the recovery of vegetation (coverage, production, quality, and diversity of species), favors the harvest of rainwater, and contributes to reducing erosion as well as to improvement in the productivity of livestock owing to a greater quantity of good quality forage (INIFAP, 2011; Genro and Silveira, 2018).

The workshop on the use of supplementary forages for the management of the rangeland represented a strengthening of the livestock activity in Tepetixtla. As mentioned by Powell and Sánchez (1979), the use of cultivated forages as supplementary feed is a method of improvement of rangelands practiced by many ranchers, who benefit through higher profits and greater ease of cattle management. However, to achieve this, the available resources, what type of forage can be adapted to the edaphoclimatic factors of the area, and what grazing system meets the management objectives and nutritional requirements of livestock must all be taken into account (Powell and Sánchez, 1979). The foregoing showed that the route in which the species preferred by livestock were recognized was fundamental to identify native species that are adapted to the region and with this, a trend similar to that found by Ibarra et al., (2018), where the sowing in degraded areas, of a supplementary forage well adapted to the study region allowed them to increase production and have more profitable and sustainable farms compared to others in the area. It is worth highlighting the role that the workshop played for the elaboration of the rangeland management plan, since it allowed participants to recapitulate what was learned in previous workshops and to form an overview of the status of the rangeland. This is very important because it gives women the elements needed to make decisions for the collective management of the resources of their community and makes them aware of the strategies to consider to achieve the sustainability of their production system.

The training of women as social actors in this process is crucial in areas where extensive livestock farming is developed, because as Ferrer (2016) has mentioned, this activity is mainly linked to mountain areas, where family and traditional farms are predominantly small, as in the case of Tepetixtla. These participatory workshops also strengthen the independence and autonomy of community organizations, which is expected to help them recover the spirit of self-managed work as the basis of just and equitable social relations, through the rational management of natural resources (OCSS, 2015). In conclusion, given the relevance of the livestock production in the community, it is possible that the integration of the women and their children who oversee this activity into a collective project, along with the training provided in the community, will strengthen livestock activities in rural areas of Mexico.

**Acknowledgements**

Universidad Autónoma Chapingo, and Organización Campesina de la Sierra del Sur for logistic and financial support. Tepetixtla people for their openness and willingness to share with the group of extension personnel.
References


KEY NOTE PAPERS
THEMATIC KETTNOTE 2

Forage production for improved on-farm wealth and wellness

Caradus, J.

Grasslanz Technology Ltd, PB 11008, Palmerston North, New Zealand

Introduction

It is often overlooked that the world’s largest agricultural land use by far is grassland, where these are mostly grazed by livestock, either domesticated or wild animals. Native grasslands are referred to as savannah (in Africa), steppe (in sub-Artic Eurasia), prairie (in North America), or pampas (in South America). Grasslands contribute to the livelihoods of more than 800 million people (FAO 2000). Native grasslands are maintained by restricted rainfall that reduces the opportunity for succession by forest. Grasslands are not only food for livestock, but also provide a habitat for wildlife, prevent soil erosion, support pollinators, and capture carbon which can then be sequestered into the soil through composting of leaf litter.

The world’s grasslands and the way in which they are used can be categorised in a number of ways:

- Natural or native versus cultivated and sown
- Temperate versus sub-tropical versus tropical
- Arid through semi-arid
- Coastal plains to alpine meadows
- Grazed versus cut and carry
- Subsistence farming through corporate farms to factory farming

Grasslands of the world have been and are primarily used for conservation, recreation, and the production of animal protein production, primarily fibre, meat and milk. Depending on the definition of grassland it is estimated that between 20 and 40% of the earth’s land area covered by grasslands (FAO 2006). That is about 4.1 to 5 billion ha (depending on definition), or about 70% of the global agricultural area (FAO 2000). The two largest producers of beef, USA and Brazil have 320 million ha and 200 million ha respectively of grazed grasslands.

Some of the world’s most productive grassland systems are on land that was originally in forest (Figure 1 shows indigenous biomes and Figure 2 the change from native to modified grasslands). This change in vegetation cover includes much of western Europe, eastern USA, large areas of South America and smaller regions such as New Zealand and the eastern coastal area of Australia. Native forests once covered 80% of New Zealand, but today they cover 26%. In 2019, there was world-wide concern for the loss of forest in the Amazon sparked by disgruntled landlords or leasees seeking a change in land use which included an increase in grassland for grazing livestock. This dramatic large scale change in land use has sparked global concern.

While cultivated grasslands are of significance in supporting protein supply to a growing world population there is now a mounting debate on the environmental impact of grassland farming and whether it is a
sustainable option (FAO 2006).

Figure 1. Indigenous or original vegetative biomes

(https://askabiologist.asu.edu/explore/biomes)

Figure 2. – Remaining native grasslands and modified and sown grasslands. (https://forages.oregonstate.edu/nfgc/co/onlineforagecurriculum/instructormaterials/availabletopics/grasslands/definition)
Threats to the continued use of grasslands

A review undertaken in 2018 (Sapere Research Group) identified 3 global mega trends likely to affect the future of food and farming:

1. Enhanced environmental consciousness - global consumers are increasingly demanding products that fulfil a growing range of environmental demands.

2. New technological developments and transformational science - these developments include advances in the science of genomics, plant-based proteins and cellular agriculture.

3. Changing consumer preferences – with an increased demand for quality, food safety, health benefits, provenance, ethics and biosecurity.

So what does this mean for the future of grassland and grassland farming? New Zealand’s dairy herd has doubled in the last two decades to 6.5 million animals, nearly all of which graze forage outdoors year-round. But this trend has started to change with the challenges from artificial (non-animal) protein and operational constraints to minimise negative environmental impacts. An ambitious plan called the Global Deal for Nature has been proposed to prevent the world’s ecosystems from unravelling which encourages countries to double their protected zones to 30% of the earth’s land area, and add 20% more as climate stabilization areas, for a total of 50% of all land kept in a natural state (https://www.nationalgeographic.com/environment/2019/04/science-study-outlines-30-%-conservation-2030/).

One western world perspective is that pastoral agriculture is on the road to extinction and the biggest challenge to pastoral farming is the social license to continue to farm. This is largely associated with an increased demand for environmental integrity and animal welfare (Stafford et al., 2002). In many countries environmental integrity is focused on protecting waterways from leached nutrients, particularly nitrogen, and from reducing methane gas emissions from ruminants (Foote et al., 2015). New Zealand agriculture faces significant concerns in the form of changing consumer tastes and increasing regulatory compliance as health and environment factors are increasingly prioritised.

Other threats include:

- Artificial laboratory based and plant protein and the future of the grazing animal
- Social attitudes driven by the rural urban divide
- Urbanisation and encroachment of cities onto fertile farmland
- Research capability, resources and funding devoted to grassland research is diminishing
- Land degradation through nutrient depletion and erosion in natural and cultivated grasslands
- Impacts of changing climate and global pandemics

Pastoral agriculture and grassland productivity, like other parts of society and economies, has been significantly disrupted by the COVID19 pandemic. Both supply and demand have been affected, although as a result of lockdowns, closed borders, travel restrictions, and social distancing rules imposed in many countries the greater impact has been on demand. Logistical constraints and labour shortages have resulted in reduced access to conserved animal feed and slaughterhouse capacity, and led to the destruction or waste of perishable items that are unable to be stored (Nicola et al., 2020; Siche 2020). In many countries the closure of restaurants and street food outlets removed a key market for many producers and processors, resulting again in deceased demand and lower prices at the farmgate. Efforts were made to keep agriculture safely running as an essential business so that at least local markets could be reliably supplied with affordable food. However, food insecurity was inevitable in countries which also had to manage fragile economies, internal conflicts, extremes of weather, and locust plagues.

Social attitudes driving the rural urban divide may be more imagined than real. A recent survey of more than 1000 people found New Zealanders are almost five times more likely to hold a positive view of sheep and beef farming than a negative one (https://farmersweekly.co.nz/section/agribusiness/view/they-like-you). And they are more than twice as likely to hold a positive view of dairy farming than a negative one.

The best antidote to disruption in farming is to innovate and continue to have the capacity and capability to innovate. This is largely about mitigating the risks, and delivering agritech solutions for a prosperous future. So what is being and can be done?

- Use of alternative forages – e.g. plantain to mitigate nitrogen losses to waterways
through reduced rumen ammonia production (Navarrete et al., 2017) and reduced urinary nitrogen content (Chen et al., 2017)

- Use of microbial endophytes to improve adaptation to biotic and abiotic stresses (Johnson and Caradus 2019)

- Attempts to increase species diversity in managed grasslands (Tilman et al., 2014)

- Systems for real time monitoring of waterways and catchments leading to improved management of environmental impacts (Hodges et al., 2018)

- Reducing stocking rates in vulnerable catchments but increasing the value for the animal products produced (Sharma 2019). Largely this relies on the use of manufacturing and production processes to provide a product where the consumer is willing to pay a premium over a similar but undifferentiated product. This can occur both on-farm and off-farm through cooperative business ventures, but does require a different set of skills to those required for production farming.

- Improved management of effluent systems such as the ClearTech system being trialled at the Lincoln University Dairy Farm, Canterbury, NZ (Cameron and Di 2019).

- Artificial intelligence has been predicted to have a significant impact on agriculture over the next decade, although its genesis occurred in the 1980s (McKinion and Lemmon 1985). This will include the increased use of apps, sensors for disease, pest, crop and environmental monitoring/forecasting, smart alerts, decision support systems, machine learning, drones and robotic systems and increased automation.

**Forage production systems - variety, distribution and scale**

In many regions, including east Africa, central Asia, central South America and parts of the Australian interior, there is extensive use of native grassland for animal grazing. In eastern Africa about 75 % of land area is dominated by natural grasslands, often with a varying amount of woody vegetation, and have been grazed by livestock and game for millennia (Figure 3). Brachiaria species, which are native to eastern Africa, have been extensively sown in tropical regions, such as large parts of Brazil and northern Australia, but only recently viewed as an option for parts of Africa.

![Figure 3. Impala and zebra grazing on native grasslands in Kenya](image-url)
Perennial ryegrass (*Lolium perenne*) a native grass of Europe is used extensively in temperate regions of the world because of its high nutritive value. In higher rainfall regions of Australia about six million ha and in New Zealand about ten million ha have been sown to perennial ryegrass. Tall fescue, a native of Europe and northern Africa, has been widely used in cultivated pastures in North America, eastern Australia and southern South America. Temperate grasses are often sown with legumes such as white clover, red clover or annual clovers in drier areas, because increasing legume content of grazed pasture leads to improved animal productivity (Harris *et al.*, 1997; Dineen *et al.*, 2018; McClearn *et al.*, 2020). However, lucerne, or alfalfa, is the most widely used legume and is generally sown as a monoculture in cut and carry systems.

**The demand for increased diversity in grassland landscapes – is this important?**

Cultivated grasslands are often sown to a small number of species, in distinct contrast to native grasslands which are often a complex ecosystem of many species. Improved ecosystem functionality and stability is postulated to occur with increased biodiversity (Tilman *et al.*, 2014). However, can species diversity add any economic value to grazed grasslands? While grassland diversity restoration management increases the resistance of carbon fluxes to drought, it also reduces agricultural yields, revealing a trade-off for land managers (Cole *et al.*, 2019). Using data from the longest-running biodiversity experiment in the world, which is at Cedar Creek Ecosystem Science Reserve Binder *et al.*, (2018) modelled the ecological production function which quantifies the relationship between ecological inputs and particular ecosystem outputs. They found that even a risk-neutral, profit-maximizing landowner would favour a highly, but not maximally, diverse mix of 11 species. The relationship between diversity and primary production has been assessed at 3 geographically diverse sites, and include California annual grasslands, and old fields in New York and grasslands in the Serengeti (McNaughton 1993). A negative relationship was observed between productivity and diversity in the annual grasslands of California and the old fields of New York, while there was no relationship between productivity and diversity was found in the Serengeti. Conversely, Tilman and Downing (1994) observed that the effect of perturbation on production was maximised in simple systems and minimised in the most diverse systems. So is the jurying still out on the importance of diversity due to a lack of consistency from known results?

**Have we reached the limits of genetic gain through phenotypic selection and breeding?**

Estimates of genetic gain for key traits (yield, quality and persistence) in forage species due to plant breeding has been considered to be up to about 6 per decade (Wilkins and Humphreys 2003), but can be variable (Table 1), with genetic gain higher in white clover than red clover and lucerne (Woodfield and Brummer 2001). For comparison genetic gain in grain yield potential of wheat have been estimated to be approximately 11 per decade (Graybosch and Peterson 2010).

**Options for improving grassland and forage production**

If one considers that the measured genetic gain through conventional phenotypic selection is either too low or not realised on farm, then what other options are available to ensure future productivity within allowable and acceptable environmental constraints?

- **Endophytes and microbial symbionts:** In New Zealand, Australia and parts of USA the persistence of perennial temperate grasses is heavily reliant on the presence of an obligate mutualistic fungal endophyte (*Epichloë* species) (Caradus and Johnson 2019). This endophyte produces secondary metabolites that protect the plant from insect pests and provides improved

**The role of legumes and herbs in grassland**

As mentioned above, legumes in mixed grass swards are known to increase sward nutritional quality resulting in increased animal production (Harris *et al.*, 1997; McClearn *et al.*, 2020). They showed that the presence of white clover was associated with both an increased feed intake and the higher nutritive value of the clover. Over the past 20 to 30 years the enthusiasm for introduced legumes in managed pastures has ‘waxed and waned’ largely due to the increased availability of cheap nitrogen fertiliser. For intensive systems this has provided an increase in grass production that is easily and quickly captured in animal production, particularly for dairy farmers. However, the increased public awareness of the unintended consequences of this practice leading to poor water quality has resulted in calls to reduce nitrogen inputs and return to using biologically fixed nitrogen through the inclusion of legumes in grazed pastures. While this may not automatically reduce the leakage of nitrogen in rivers and water ways it is considered ‘more natural’ and hence more acceptable.
tolerances to some abiotic stresses, such as drought. Other microbial options need to be explored and developed for other forages to improve adaptation and resistance to both biotic and abiotic stresses.

Table 1. Estimates of genetic gain for yield due to breeding in a number of forage species.

<table>
<thead>
<tr>
<th>Forage species</th>
<th>Estimated genetic gain for yield per year</th>
<th>Region</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perennial ryegrass</td>
<td>0.25 - 0.73</td>
<td>New Zealand</td>
<td>Woodfield 1999</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>New Zealand</td>
<td>Easton et al. 2002</td>
</tr>
<tr>
<td></td>
<td>0.7 (summer/autumn)</td>
<td>New Zealand</td>
<td>Easton et al. 2002</td>
</tr>
<tr>
<td></td>
<td>0.1 (spring)</td>
<td>New Zealand</td>
<td>Easton et al. 2002</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>Europe</td>
<td>Wijk and Reheul 1991</td>
</tr>
<tr>
<td>Annual ryegrasses</td>
<td>1.5</td>
<td>New Zealand</td>
<td>Easton et al. 2002</td>
</tr>
<tr>
<td>Tall fescue</td>
<td>0.1 to 0.55</td>
<td>Europe</td>
<td>Veronesi 1991</td>
</tr>
<tr>
<td>Lucerne</td>
<td>0.26</td>
<td>Central USA</td>
<td>Hill et al. 1988</td>
</tr>
<tr>
<td></td>
<td>0.18 and 0.22</td>
<td>Northern USA</td>
<td>Holland and Bingham, 1994</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>USA</td>
<td>Loiselle 1992</td>
</tr>
<tr>
<td>White clover</td>
<td>1.21 – 1.49</td>
<td>New Zealand</td>
<td>Woodfield 1999</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>New Zealand, South Africa, Czechoslovakia</td>
<td>Caradus 1993</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>New Zealand</td>
<td>Woodfield and Caradus 1994</td>
</tr>
</tbody>
</table>

Hybrid breeding systems: The majority of perennial grass species are outbreeding and so the development of inbred lines to produce a hybrid with increased heterotic vigour has been a challenge (Woodfield and Brummer 2001). Two systems have been explored with limited success and as yet there are few commercialised options.

1. Semi-hybrids – in some outcrossing species such as perennial ryegrass severe inbreeding depression occurs when developing inbred lines and so hybrid vigour is better captured by crossing populations with very different genetic backgrounds (Brummer 1999). The production of a semi-hybrid as first generation certified seed could be achieved by sowing a mixture of basic seed of two cultivars (Barrett et al. 2010).

2. True hybrids which involves the use of cytoplasmic male sterility systems which result in failure to produce functional pollen (Havey 2004) has been successfully used in field crop breeding (Bohra et al. 2016). Use in perennial outcrossing forage crops is still theoretically possible but has not yet become a commercial reality (Islam et al., 2014).

- Speed breeding: By using prolonged photoperiods the developmental rate of plants can be accelerated to allow multiple generations per year rather than the 1 or two for field grown plants (Watson et al., 2017). This has been achieved with annual crops plants, but for perennial outcrossing crops only computer simulations have been used and these show that additional genetic gains can be achieved from speed breeding, but methods to mitigate inbreeding are required for optimal outcomes (Jighly et al., 2019).

- Phenotyping systems: Persistency is an important evaluation criterion for perennial...
forage breeding programs along with forage yield and quality, but can be difficult to measure by eye. Recent advances in digital photography and image analysis software, remote or proximal digital imaging provides opportunities for improved vegetation data collection and analysis (Luscier et al., 2006; Walter et al., 2012) including persistence where ground cover is imaged remotely to determine persistency (Borra-Serrano et al., 2018).

- Genomic selection: Genomic selection has been successfully used in animal and crop breeding and has the potential in forages for selecting key traits that are difficult or expensive to assess, or can only be measured after a period of time, e.g. plant persistence. The main benefits expected from genomic selection in forage grasses and legumes are to increase selection accuracy, reduce cycle time, and potentially reduce evaluation costs per genotype (Resende et al., 2014). A number of publications have propositioned that genomic selection will deliver major advances in improved yield, quality and persistence of grassland species (Hayes et al., 2013). However, to date the promise of genomic selection in forages is yet to be realised.

- Gene editing techniques such as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) allow for the insertion, removal or replacement of genes at predetermined sites in the genome (Richter 2016) and is being used to precisely design crop plants (Wang et al., 2014; Komor et al., 2017). The same could be achieved for grassland species (Fritsche et al., 2018). In many countries gene edited plants are still viewed as genetically modified and subject to regulation, although there is increasing momentum for them to be de-regulated (Pei and Schmidt 2019). This has occurred already in some countries where gene edit has not resulted in inserting foreign DNA.

- Transgenics plants have been genetically engineered or modified using recombinant DNA techniques to create plants with new traits and characteristics. This technology has been used extensively in crop plants such as soybean, cotton, maize and canola but while experimented with in grassland and forage species there are few commercialised examples. The notable exceptions are for lucerne with Roundup Ready alfalfa® and HalvXtra® (low lignin) alfalfa both marketed (Undersander 2010), making up about 30 of the total lucerne market in USA.

Concluding comments
Sustainably increasing grassland productivity through creating more from our resources while staying within environmental limits is a key to raising living standards globally. However, grassland farming faces significant challenges from consumers, environmentalists, government policies, and new technical options. Integrating the large number of agritech developments into current pastoral systems will in itself provide challenges to farmers and society as a whole. Yet without that being achieved threats to the sustainability of grasslands will increase. There is much for us as grassland researchers to understand and manage so that the world’s grasslands both natural and man-made have an enduring future.

References


Thank you, Chair. Good morning. Good afternoon. Good evening, good night, from wherever you have joined. I had hoped to be amongst the welcoming party to this Congress in Kenya, when it was originally planned. Unfortunately, with COVID-19, that was not to be. But I want to thank those who have persevered to ensure this Congress proceeds as it is right now. So thank you for the opportunity to speak today.

I would like to talk about ruminant livestock production systems, and imperatives for sustainable development. I would like to discuss this in the context of three dimensions. First, the context of ruminant production systems: the controversy, diversity, and development opportunities. Then talk a bit about the rangeland trends and threats, and then the imperatives that we must embrace, harness diversity and engage widely.

So first, ruminant production systems. As you know, livestock systems touch on almost all of the important issues and the development context at this time, zoonotic diseases, Anti-Microbial Resistance (AMR), water, welfare, waste, nutrition, greenhouse gas emissions, food safety, and biodiversity. So it’s not surprising that livestock is caught up with so many controversies. Those related to food—in which the controversy about those who eat too much is spilling over into those who eat too little. There is the controversy about the environment and the emissions that livestock produce, and other means of degrading the environment. Some of this, of course, is not all based on facts, but sometimes on sensationalization.

But it is true that livestock emit greenhouse gases, and we must respond to this charge. The controversy about livelihoods, for those who say if we want to save the planet, we must get rid of all the livestock, they do not see livelihoods as part of the scheme. And of course, health, in which the current pandemic tells us about the interface of livestock and human health.

So many controversies that the livestock sector must address. Yet, we must remind ourselves, lest we become consumed by the pessimism, that ruminant systems provide diverse benefits to many, many people—not only to meat and milk, but about half of the fertilizers in South Asia, particularly nitrogen, come from livestock, fuel income. Here in Kenya, there are many stories about how dairy paid for university fees and so on. And the social and cultural aspects and other products such as hides and fiber. And of course, notwithstanding the greenhouse gas controversy, some ecological services.
So the benefits of livestock are numerous and accrue to a large number of people, as I would mention in a little bit. Just take the issue of food – as you can see the green bars associated with grazing systems in various regions of the world – contribute significant food and nutritional security.

Food in terms of quantity. Most food in low- and middle-income countries, both plants and animal products, are produced by smallholders and mixed crop livestock systems. So, here is not only the food, but the livelihoods question.

Ruminants raised on rangelands produce most of the red meat here in Kenya, over 90% of it. And we should not forget the unique nutritional qualities of livestock products, which are essential particularly for the young, who could be irreversibly stunted if they do not get sufficient dense nutrients from sources such as livestock.

I have already referred to the environmental impacts, where there are both challenges and opportunities. In this map we show the emission intensity per unit of land, with the darker red being most intense. These systems are numerous, spread around the world. And it is true that emissions intensity are highest in the developing countries.
who depend on livestock. There are means to reduce that by increasing livestock productivity, of course. So the climate smart production, greenhouse gases, must be addressed.

This is the time when we’re all concerned about climate change, and livestock must play its role in dealing with this issue. There are many opportunities to ‘net-off’ emissions in rangelands through carbon sequestration. And we must note that despite the controversies about water in these rangelands, it’s ‘Green’ water, which are not consumed by anyone else. So the scale and importance of ruminant systems to livelihoods should not be overlooked.

But I want to be sure that we do not overlook the fact that the impact or the dependence on livestock is widespread. More than a billion people worldwide gain their livelihoods from livestock. Half of these depend on animals for a multitude of benefits, as I’ve shown in the previous slide. Over 200 million households are located in rangelands, fragile environments, where they depend on livestock. Women head up two thirds of the crop livestock households in rural areas. And in places where women are not allowed to own land, and other kinds of assets, they can own livestock. This is not an insignificant opportunity for women.

I must touch on the issue of health since we’re in the period of the pandemic. It’s in these rangeland systems where human, animal and environmental help come together. That presents an opportunity for us to work in a One Health context. Investments in rangelands offer win-win One Health outcomes due to the intimate relationships amongst ruminants, people, wildlife and their lands. Grazing systems designed and managed with pastoralists ranches minimize threats and livestock, human and environmental health, while restoring rangelands for their productive potential.

Let me now touch a bit on the rangelands themselves, which, as we know, dominate in terms of landmass in the world. A recent map to which ILRI contributed, states that over 50% of terrestrial surface is rangelands. All I want you to gain from this picture is that they are numerous and widespread. And here are some facts about them. All in green, here represent the rangelands, more than 50%. They cover 80 million square kilometers, 84% of which are used for livestock production. It’s only the dark green portion of this pie chart, of the rangelands that are not used for livestock. Thirty-one million square kilometers are too dry for crops, the white part where only livestock can bring a return from these lands. About 36 million square kilometers are used for Integrated Crop livestock systems and agro pastoral systems as well. About 44% or 34.8 million square kilometers are covered by grasslands, the discussion of the previous speaker.
These rangelands offer two pathways, one towards increasing food production and another towards environmental stewardship with a lot of interplay between these two. Let me offer some more facts about rangelands, notwithstanding the issue of degradation, it is true that they have been largely stable. In 73% of these rangelands, productivity has been stable, and in 17% of them, productivity improved, only in 6% was productivity reduced. That is the case too, for land cover and soil where 99% remained stable and 93% of the soil organic matter are stable. So although there is great concern about rangeland degradation, there is also considerable stability.

However, there are threats to rangelands – through fragmentation pressure to fragmented rangelands, to more intensive land use, fencing, conversion to cropping, road infrastructure, urbanization, mining. All threaten rangelands and could lead to fragmentation. With climate change as well, 12% of rangelands will lose about over 20% of the growing period. About 16% will have maximum temperatures above 35 degrees, while 31% will surpass one or more of the three climate thresholds. And 75% of the livestock losses in rangelands are through droughts. These are particularly fragile systems.

There is also concern about biodiversity losses. Rangeland biodiversity losses are increasing due to climate change, crop expansion, fragmentation and all the other issues that encroach on them as fragmentation progresses. Marginalization is also a concern, particularly for pastoralists who have been neglected through policy neglect for many, many years, and are seen as a backward system, notwithstanding the high input-output ratio that is derived from these systems.

So, as we respond to the challenges, we must pursue at least three imperatives. These imperatives are aimed at mitigating the threats and to realize the opportunities, we must embrace change.

Livestock are not all positive, there are negatives. So we must respond not only today to increasing demand for meat and milk, but we must also address sustainable practices. We must contribute to environmental solutions. We must harness the biodiversity and diversity as a whole; prioritize and target pathways for ensuring equitable development; solve major constraints such as resilience, improving resilience, improving land use, addressing forage scarcity and addressing access to market issues; we must engage widely beyond our natural confines.

Beyond Science or in research, we must engage governments and development partners who will help us to scale solutions. Beyond livestock partners, we must work to achieve wider development outcomes. As livestock people, we’re far too accustomed to speaking to our own. The issues that we must address are of global significance, and we must do more to engage on these. So let me, in coming to a close, discuss two pathways for ensuring equitable rangeland development.

Distinguishing these two pathways are: where rural rangeland resources are more favorable for food production, we pursue opportunities to increase sustainable livestock production and market engagement; where rangeland resources are less favorable for food production, we can focus more on supporting environmental stewardships.

Note, greater risk mitigation, resilience and adaptive capacity are needed in all rangelands, depending on the pathway we choose. As circumstances evolve, a mosaic of rangeland development pathways is likely to emerge. Let me just give two examples where science-related inputs are making a difference, particularly to resilience. As I mentioned earlier, drought is the most important loss of livestock in rangelands. Through an insurance scheme, targeting pastoralists, using satellite data to estimate forage on the ground and link to an index, mortality rates can be projected and payouts can be triggered as droughts progress, and mortality and morbidity rates are projected. This is one way to build resilience. They do not prevent droughts, but they allow pastoralists to adapt to droughts and to recover faster.

We are also aware in the rangeland degradation context, of the tragedy of the commons, where in all “owned by” and “managed by” communities there’s little opportunity to invest or to take care of these rangelands. But we can, through community approaches, address these concerns and have whole communities work together to address degradation and improvement of rangelands. These are two examples.

As we go forward, we must ensure that these rangelands sequester more carbon and contribute to a reduction of the livestock footprint around the world. More investments are needed in this context.

So let me conclude and share few messages. Rangelands are an essential part of the complex and diverse livestock production systems that are essential for development. With this group, we all know that rangelands present many sustainable development opportunities. But there
are challenges and we must embrace those, we must address them. To realize these opportunities and mitigate these threats, we must embrace the change I alluded to. We must harvest the diversity which exists and we must engage more widely beyond our circles of comfort.
THEME KEYNOTE 4

Ecological Science Infrastructure for Sustainability Transformations in Rangelands


1. USDA-ARS Jornada Experimental Range; 2. USDA Natural Resources Conservation Service; 3. Green Gold Mongolia; 4. USDA Southwest Climate Hub; 5. National University of La Pampa; 6. New Mexico State University

Key words: Big data; collaborative management; monitoring; remote sensing; state-and-transitions

Abstract

Sustainability transformations—deliberate and radical shifts in values, governance, and management regimes to achieve sustainability—are needed in rangelands as in other components of the Earth system. We review four concepts comprising an ecological science infrastructure to support such transformations. The foundation is standard measurement of rangeland conditions in the field, especially vegetation and soil properties that underpin the environmental aspects of sustainability. Big data resources, especially gridded spatial datasets produced by models and remote sensing, can be combined with field data and computational approaches to upscale information about rangeland conditions and produce additional indicators of ecosystem functions and services. State and transition models (STMs) linked to land types provide a means to interpret indicators and link interpretations to sustainable land management practices to manage change. Technologies for climate adaptation in rangelands also need to be linked to STM databases. Web and mobile technologies can put multifaceted science knowledge into the hands of pastoralists worldwide to support transformational changes in how rangelands are managed.

Introduction

Rangelands and pastoral peoples will face mounting challenges in the years ahead. Climatic change will cause increasing aridity, increasing frequency of extreme events, and decreasing productivity in many rangelands (Bradford et al., 2020; Godde et al., 2020; Zhang et al., 2020). The effects of climate change will interact with accelerating conversion of rangelands to more intensive uses, increasing the demand for resources in the remaining rangelands and reducing important ecosystem services in converted rangelands (Barral et al., 2020; Mirzabaev et al., 2019). A long standing disregard for the value of rangelands facilitates land use conversion and limits investments in management solutions (Hoover et al., 2020; Reynolds et al., 2007). Consequently, resource use-climate change interactions are poised to precipitate abrupt and undesirable transitions with long-lasting impacts on pastoral societies as well as the Earth system (Bestelmeyer et al., 2018; Menges et al., 2019; Mirzabaev et al., 2019).

The general threats to rangelands are reasonably well understood (Hoover et al., 2020). Pragmatic responses to those threats, however, are not. First, while it is clear that global change is altering social-ecological systems to varying degrees, the specific alterations that determine the severity of loss of ecosystem services, and options for adaptation or restoration, are poorly defined. The lack of specificity is especially problematic for rangelands, where human use of rangelands, that can have relatively minor impacts on biodiversity and ecosystem functions, are classified similarly to far more intensive uses such as deforestation or urbanization (Sayre et al., 2017; Williams et al., 2020). The “desertification narrative”, for example, is commonly misused such that naturally arid systems are condemned as degraded and the people living in those systems are seen as agents of degradation (Davis 2016; Prince and Podwojewski 2020). Second, the urgency associated with global change has led to calls for transformation of resource use and agricultural systems (Pereira et al., 2020). Strategies to trigger transformation, however, are frustratingly non-specific and lack local contextualization (Stafford Smith 2016) or emphasize overgeneralized and over-hyped “one-size-fits-all” solutions that are poorly matched to most local situations (Huntsinger 2016).
Specific guidelines for achieving sustainability transformations at the local level, particularly in the face of ongoing global change, is the greatest challenge facing natural resource professions. There are many facets to transformation in rangelands that must be considered, including resource use strategies, enterprise structure, power relations, governance, markets, and policies (Meyfroidt et al., 2019; Osinski 2021; Spiegel et al., 2020). In this short paper, we consider how ecological science information and technologies can be created, organized, and used to support transformations in rangelands. We base these ideas on our ongoing efforts to develop knowledge systems to support rangeland management in the U.S., Mongolia, and Argentina.

**Standard monitoring methods and data**

The foundation of science-based decision making is observation. This might seem trite, but inconsistent rangeland monitoring methodologies, compounded by a lack of investment in data management, continues to limit a clear understanding of rangeland conditions and, ultimately, what is considered “sustainable”, “degraded”, or “restored.” In the United States, standardized assessment and monitoring methods for rangelands were collaboratively developed with land management agencies and have been trained to thousands of rangeland managers worldwide (Herrick et al., 2017b). A common database structure and well-developed data management protocols ensures that vegetation and soil indicators reflect real differences in ecological conditions across space, over time, and among different observers (Courtright and Van Zee 2011; McCord et al., 2021). For example, there are now 65,000 monitoring plots globally (mostly in the U.S. and Mongolia) that use the same methods and are comparable, with time series of up to 20 years. Widely adopted standardization also offers opportunities for integration with tools for defining management benchmarks and computational tools that add information value to monitoring observations (see below). There are multiple, valid standardized monitoring systems (Oliva et al., 2020), but it is important to recognize that comparisons and benchmarks are method-dependent. Finally, we acknowledge the varying capabilities for implementing rangeland monitoring across world. For this reason, the Land Potential Knowledge System (LandPKS) mobile apps were developed using a simplified methodology that sacrifices some degree of precision and resolution of vegetation information, but is accessible to pastoralists in a wide range of socio-economic contexts (Herrick et al., 2017a).

**Big data, data integration, and upscaling**

“Big data” resources provide new opportunities for accessing information on ecological conditions from local to global extents. Big data products leverage spatial data layers, remote sensing, and standardized monitoring data to create gridded estimates of biophysical variables at fine scales (e.g. 900m²-4km²) and at a continental extent. In the case of dynamic variables, including climate and vegetation, estimates have been produced over long time periods (1984-) at annual resolution (Bestelmeyer et al., 2020). These products provide a broadened perspective on sustainability and allow upscaling of observations from points to landscapes and regions. For example, standardized monitoring data have been used to train machine learning algorithms that estimate vegetation cover and production from remotely-sensed and modeled covariates (Alldred et al., 2020; Jones et al., 2018). Using the computational power of Google Earth Engine, Landsat imagery dating to 1984 constitutes the basis for yearly and spatially continuous estimates of vegetation cover and production by plant functional group at a 30-m resolution, which users can query and visualize with a custom web application (https://rangelands.app/). Such tools can not only provide information on locations in the vast spaces between monitoring points, but they can provide information on landscape patterns needed to understand the impacts of livestock movements, spatial variations in weather, and other spatial processes (Bestelmeyer et al., 2011).

Continuous soil and vegetation predictions, in turn, can be combined with models to predict and scale up other processes of management interest, such as soil erosion. For example, bare soil cover, canopy gap distribution, and vegetation height estimates modeled in fractional cover products can be used as inputs in a sediment transport model to produce spatially-explicit dust flux estimates (Webb et al., 2020). It is important to recognize that the models underpinning such “value-added” indicators are ultimately based on (often distributed) long-term experiments carried out at research stations throughout rangelands of the world.

The integration of gridded climate data with remotely-sensed estimates of production are especially useful indicators of ecosystem function and services in rangelands, particularly Precipitation Use Efficiency (the ratio between aboveground net primary production and precipitation) and the Precipitation Marginal Response (the slope of the linear relationship between annual aboveground net primary production and precipitation) (Verón et al., 2018).
These useful indicators can be made available to land managers globally using existing open access data.

Ultimately, consideration of multiple indicators is needed to base decisions on the multiple ecosystem services provided by rangelands and the synergies and tradeoffs associated with particular management decisions (Power 2010). For example, the removal of shrubs might marginally increase grasses and livestock forage production, but at the expense of carbon sequestration, wildlife habitat value, or protection of the soil surface from wind erosion (Archer et al., 2011). Thus, what is considered sustainable should be based on multiple types of ecosystem process and ecosystem service indicators (Manning et al., 2018), yet we often judge the merits of management decisions using narrower perspectives. Big data-based indicators reflecting various ecosystems services need to be made more widely available to land managers and pastoralists around the world to enable better decisions, which is now eminently possible via cloud computing and web and mobile services (Herrick et al., 2013; Jones et al., 2018).

**Indicator interpretation via state and transition models**

While state and transition models (STMs) were initially conceived to link rangeland management to the emerging concepts of ecosystem non-equilibrium and catastrophic transitions (Walker and Westoby 2011), they have become widely used as pragmatic tools for understanding and forecasting change in many types of ecosystems (Hobbs and Suding 2009). STMs represent the multiple potential states of a particular land type, where states are defined by vegetation, soil, or other dynamic characteristics and distinctions among states reflect differences in the ecosystem services provided as well as the risks and opportunities for change in ecosystem services provision (e.g., ecological thresholds) (Bestelmeyer et al., 2017). STMs also provide an opportunity for collaboration between scientists and pastoralists and for addressing power imbalances by the inclusion of diverse stakeholders in STM development (Kachergis et al., 2013).

Three advances in STMs will increase their utility for supporting sustainability transformations. First is the development of a global web-based platform to guide STM development, which is being led by the USDA-ARS Jornada Experimental Range in partnership with the USDA Natural Resources Conservation Service and New Mexico State University. The Ecosystem Dynamics Interpretive Tool (EDIT) is a database for housing state-and-transition models linked to land classifications and spatial data to make STM information available via the web and mobile devices (https://edit.jornada.nmsu.edu/). Application programming interfaces (APIs) allow STM data to be linked to a variety of other web and mobile applications, such as LandPKS. Once STMs are developed in EDIT, a pastoralist with a mobile phone will be able to relate a location to the appropriate STM and access tools for indicator interpretation and management options. Second, STMs are being linked to quantitative benchmarks that allow standardized monitoring data to be interpreted according to STMs. For example, STMs developed for Mongolia include quantitative criteria for states based on vegetation cover indicators, such that computational “keys” can classify a monitoring record to an ecological state in a rigorous and repeatable fashion (Densambuu et al., 2018). Such rigor is essential for a community-wide understanding of progress toward or away from sustainability goals. In addition, benchmarks can be included for “value-added” and other indicators discussed earlier, such as wind erosion potential. For example, STMs could communicate how subtle changes in vegetation structure within a particular soil type create non-linear increases in wind erosion susceptibility beyond benchmark value (Webb et al., 2020). Third is the linkage of STMs to sustainable land management (SLM) practices and other tools (Briske et al., 2017; Giger et al., 2018). STMs can provide a logic that winnows practices that are mismatched to the reference conditions and ecological drivers and feedbacks bearing on a particular state transition. For example, one would not consider a woody plant removal practice as progress toward sustainability for an STM in which woody plants characterize the reference state (Rommel et al., 2009). The construction of a comprehensive database of evidence-supported SLM practices for rangelands that can be linked to STMs will be a priority of ours for the coming years.

**Climate adaptation to steer transformation**

The “elephant in the room” facing local sustainability transformation is how to cope with social-ecological drivers emerging from broader scales that cannot be affected by management decisions. State transitions associated with regional changes in climate and hydrology (i.e. novel ecosystems) do not have restoration options, only adaptation options. In this sense, adaptation is a means to direct inevitable transformation along the most desirable course available, even if we’d prefer to avoid transformation altogether (Bestelmeyer and Briske 2012). A variety of...
rangeland adaptation and mitigation strategies have been developed including traditional options at the enterprise, human and social levels (Joyce et al., 2013). In addition, novel technological solutions are emerging. Especially promising in rapidly responding to changing climatic conditions is the application of technological monitoring solutions and precision technologies, such as phenocams (Browning et al., 2019) and sensors for dust monitoring, cattle tracking, trough water level surveillance and fine-scale precipitation variability monitoring (Spiegal et al., 2020). Agrivoltaics, or producing solar energy in combination with agricultural enterprise and dual land uses, such as wind energy or bioenergy (i.e. algae), are creative options for novel, non-traditional revenue streams and reducing reliance on traditional energy sources.

A recent inventory by co-author E. Elias found more than 520 livestock and rangeland decision tools globally. A simple process to allow managers to find the most useful of these tools to address their local management challenge is critical to support climate-informed decision-making. Web-based and mobile tools, such as EDIT and LandPKS described earlier, could help serve this role. “Big data” type tools, such as Grass-Cast that provides an annual projection of above ground net primary productivity at a local scale, could be used for coping with climate uncertainty in rangelands throughout the world (Hartman et al., 2020).

Conclusions

Development of an ecological science infrastructure to support sustainability transformations in rangelands should be a priority for international rangeland science community, and similar calls have been made in the past (Verstraete et al., 2011). The proposed infrastructure is complex, but we now have the accumulated science, technologies, and ideas to make it a reality. The vision for the infrastructure we described is also incomplete, as societal indicators and benchmarks should also be included as well as mechanisms for using this infrastructure in collaborative decision-making (Reid et al., 2021). We also need to mobilize government, academic, and industry resources to support these uses. Nonetheless, our proposal can support a new narrative for the role of ecological science in rangeland (and dryland) sustainability. Not a story of degradation and helplessness that leads to paralysis and not Pollyannish silver-bullet solutions that distract and detract from real progress. In the words of (Stafford Smith 2016), “we need a narrative that presages solutions and empowerment”. Thoughtful organization of technological resources can be a part of this new narrative.

Acknowledgements

These ideas have been supported by the USDA Agricultural Research Service Long-Term Agroecosystem Research Network, USDA Natural Resources Conservation Service, US Bureau of Land Management, USDA Southwest Climate Hub, and Swiss Corporation for Development and Cooperation.

References


CONCURRENT SESSION 4

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Grazing, Soil Nutrient and Properties
Carbon and nitrogen pools in soil aggregates were affected by grazing component —— results from dry and wet sieving methods

Liu, N; Wei, Y.Q; Pang, Y; Wei, B; Zhang, Y.J.

* College of Grassland Science and Technology, China Agricultural University, 100193, Beijing, China

Key words: defoliation; trampling; soil aggregates; soil carbon

Abstract
Grazing intensity can affect soil carbon (C) sequestration in semiarid grassland, but less is known about the effects of grazing component (defoliation, trampling, excreta return and their combinations) on the C and Nitrogen (N) in soil aggregates. In this study, a simulated grazing experiment was established in a typical steppe of Inner Mongolia, and we investigated the impacts of different grazing component treatments on the different size of aggregates distribution and their C and N content from dry and wet physical separations. Different soil C fractions were showed in different sieving method. The C content of different aggregate size showed microaggregates (250-53μm, 7-17%)>macroaggregates (>250μm, 4-12%)>fine fraction (<53μm, 0.4-3%) when dry sieving method was performed, but wet sieving resulted in the higher C content in microaggregates (6-14%) and fine fraction (5-11%) than macroaggregates (1-5%). N content of different size of aggregates showed similar trend with C content. The results revealed that grazing component had a marked impact on soil fraction and C and N content with the significant decreasing percentage of macroaggregates and their C and N storage under defoliation. Our result indicated that both dry-sieved aggregates and water-stable aggregates should be concerned to evaluate the short-term grazing disturbance on C and N distribution in soil aggregates. Furthermore, we suggest that trampling is critical for the soil compaction, but defoliation may play a more important role in soil aggregation and C storage in grazing grassland.

Introduction
Globally, grasslands comprise approximately 40% of the earth’s land area (Wang and Fang 2009), and provide important ecosystem services including soil conservation and carbon (C) sequestration (Zhou et al., 2017). Grazing, as a most common utilization of global grasslands, is a key factor to control soil C (McSherry and Ritchie 2013).

Soil aggregation is a key ecosystem process which is important for carbon storage, greenhouse gas emissions and other soil functions (Six et al., 2004, Wang et al., 2014, Wang et al., 2019). It is reported that, compared to grazing exclusion, the continuous livestock trampling together with less input of organic matter from plant from grazing may result in restraining the formation of soil aggregates and lack of physical protection for soil C (Wiesmeier et al., 2012), which is particularly severe in arid and semi-arid ecosystems (Duniway et al., 2018). Heavy grazing could disturb soil and leave more bare soil can result in a rapid decline in soil aggregate stability and a greater risk of runoff and erosion (Savadogo et al., 2007, Shaver et al., 2018). However, it was also found that grazing leads to well aggregation and greater soil C stock probably because of higher plant productivity, litter input and soil microbial activity (Li et al., 2007, Teague et al., 2011, Silveira et al., 2014).

Grazing involves three mechanisms - defoliation, dung and urine return, and trampling, which alone or in combination affect plant attributes and soil process of grassland (Liu et al., 2015), and the effects of these component or combination vary both in magnitude and direction, conflicting results happened (Mikola et al., 2009, Lezama and Paruelo, 2016). The previous studies all relied on the comprehensive effects of grazing, but as far as we know, there is no manipulative experiments to disentangle the relative role of these three components on soil aggregation and their C and N storage. Because trampling has supposed to directly disturb of soil, it will be the major role in regulating soil aggregation. Given that defoliation, opposite to nutrient addition, changing plant growth and coverage and leading to altering C input from plant which is important
for soil aggregation and C stable, we proposed that defoliation will aggravate the negative effects of trampling, but dung and urine return might mitigate these negative effects.

Materials and Methods

Our study was conducted in a semiarid grassland located at the Duolun Restoration Ecology Research Station in Inner Mongolia, China (42.02 N, 116.17 E, 1324 m a.s.l.). The dominant plant species are perennial plants, including Stipa krylovii, Artemisia frigida, and Leymus chinensis.

A simulated grazing experiment was established in 2015 with 64 plots (each 4 × 4 m) at the study site in randomized block design with eight blocks, including factorial combinations of defoliation (M; no mowing vs. mowing), a liquid mixture of dung and urine addition (D; no addition vs. addition), and trampling (T; no trampling vs. trampling). The details of the experimental set-up have been described in full in Liu et al., (2015).

Three soil cores (diameter 5 cm and 0-10 cm of surface layer) were collected from each plot on mid-August after three years’ implementation to estimate the soil aggregation and their carbon and nitrogen content. Air-dried soils were sieved through a 2-mm screen and removed the roots and organic debris. Firstly, the dry-sieving method was performed. Briefly, 80g air-dried soil was taken on a nest of sieves (250μm and 53μm), mounted on a vibratory sieve shaker AS200 (Retch, Germany), and then aggregates of different size classes were weighed. For the wet-sieving, an 80g subsample was gently submerged in deionized water for 3min before sieving. Floating plant debris was removed, and then the soil suspension was passed through a nest of sieves (250μm and 53μm) in the same sieve shaker with running water for 5min to ensure finally the water is clear. Aggregates retained on the sieve (200-25μm as macroaggregates, 250μm-53μm as microaggregates) and the rinse solution (<53μm as primary particle) were transferred in a pre-weighed beaker for drying. All aggregates with different size classes were dried at 65°C and weighed. The bulk soil and all fraction of aggregation were analysed carbon and nitrogen contents (Elementar, Germany).

Linear mixed models were employed to test the effects of defoliation, trampling, dung and urine return and their interactions (fixed explanatory variables) and block (random effect) on C and N content of soil aggregates and using the ‘lme’ function in package nlme of R software (Version 3.5.1).

Results

For dry-sieved, it showed microaggregates (250-53μm, 7-17%)>macroaggregates (>250μm, 4-12%) >fine fraction (<53μm, 0.4-3%) (Fig.1). Defoliation significantly increased C and N content in primary particle (P<0.05, Fig.1). For wet-sieved, it showed the higher C content in microaggregates (6-14%) and fine fraction (5-11%) than macroaggregates (1-5%). Defoliation significantly decreased the C and N content of macroaggregates and increased N content of primary particles (P<0.05). Dung and urine return significantly decreased C content of primary particles (P<0.05). A significant defoliation × trampling interaction was found in our study due to defoliation decreasing N content of macroaggregates in no-trampling plots (M×T, P<0.05, Figure 1).

![Figure 1: C and N content of dry-sieving and wet-sieving aggregates under different treatments after three years field experiment. * P<0.05, **P<0.01, ***P<0.001. CK: control, D: dung and urine return, M: mowing, T: trampling, MD: mowing + dung and urine return, MT: mowing + trampling, TD: trampling + dung and urine return, MTD: mowing + trampling + dung and urine return.](image-url)
Discussion
In our study, the performance of dry-sieved macroaggregates, which were prone to wind erosion in the semiarid grassland (Larney et al., 1994, Ciric et al., 2012), are pronounced to be disrupted compared to water-stable aggregates. Therefore, in arid and semi-arid ecosystems, both dry-sieved aggregates and water-stable aggregates should be concerned in the future study. Contrary to our expectation, we found that trampling did exhibit soil compaction, and the effect is equivalent to that under moderate grazing intensity from previous study in the same region (Ren et al., 2018), but it did not alter the soil aggregation. However, defoliation was the key factor controlling soil aggregation and their C and N. This may have resulted from plant removal and C inputs decreased suffering defoliation (Blankinship et al., 2016). The previous studies from the real animal grazing speculated that the decrease of soil aggregation probably mainly due to trampling (Wiesmeier et al., 2012, Wen et al., 2016), but our results gave the experimental evidence from simulated grazing treatment that soil aggregation suffered severely from defoliation. Our results found that the effects of trampling on soil aggregation were negligible, even positive on N content of water stable macroaggregation in mowing plots (significant interaction between defoliation and trampling). It was proved that the effects of trampling on soil aggregation and their C and N distribution were limited in semiarid ecosystems, while the worse negative effects of animal trampling on soil structure was occurred in wet or extremely wet conditions (Greenwood and McKenzie 2001). Another possible mechanism was that trampling may promote litter and standing dead mixed with soil and the process of biodegradation resulting in more litter C into soil (Wei et al., 2021, Wang et al., 2017).

Understanding the relative role of grazing components on soil aggregation and C distribution is important for understanding the underlying mechanism of soil C sequestration under grazing. Results from our field study highlight avoiding excessive consumption of plant was vital for soil health and C storage.

Acknowledgements
We are grateful to the Duolun Restoration Ecology Station of the Institute of Botany of the Chinese Academy of Sciences for providing the research sites. The work was supported by the National Natural Science Foundation of China (31971748 and 31830092) and innovation talent plan of national forestry and grassland science and technology from National Forestry and Grassland Administration (2019132608).

References


Influence of seasonality and agricultural practices on soil microbes in Kamishihoro, Japan

Madegwa, Y1; Uchida, Y2

Graduate School of Agriculture1, Hokkaido University, Research Faculty of Agriculture, Hokkaido University2

Key words: land use; season; fertilizer; microorganisms; sequencing

Abstract
Soil microbes are important for maintenance of soil fertility and ecosystem functions. Agricultural practices such as land use, seasonality and fertilizer application affect the soil microbial community structure. However, the effect of these management practices on soil microbes and related functions, especially in one specific region, is still not clear.

Therefore, the study was conducted in Kamishihoro, Japan, to determine the effect of land use (cropland, grassland), season (summer, spring) and fertilizer (anaerobic digestate, control) on soil microbial community and functions. Experimental procedure included DNA extraction, quantification, purification, amplification of 16SrRNA (bacterial gene) and Next Generation Sequencing (Ion PGM). Data analysis included Qiime-bacterial community structure, PICRUST-bacterial functional diversity predicted based on 16S rRNA data and STAMP- statistics.

Results showed that land use had the strongest influence on microbial communities, with higher relative abundance recorded in grassland in phyla Nitrospirae, Crenarchaeota etc. At family level, grassland had microbes that were found in cropland and 244 more unique microbes. Effect of season was higher in cropland in phyla Acidobacteria, Nitrospirae etc. At family level, summer had more unique microbes in cropland and spring had more unique microbes in grassland. Land use had a significant ($p < 0.05$) effect on more soil functions related to metabolism, cell communication among others, compared to season and fertilizer. Effect of season was more pronounced in cropland on functions related to metabolism, biosynthesis etc. Although on few functions (4), fertilizer had significant ($p<0.05$) effect in cropland and grassland related to transcription and metabolism.

The study showed that land use was the most important factor in determining soil microbial community structure and functions, compared to season and fertilizer. Specifically, grassland had higher relative abundance and functionality compared to cropland. Future research should consider long term effects of imposed treatments on the same.

Introduction
Soil microbial communities are significant to the maintenance of soil health by providing ecosystem services (Singh et al., 2014), such as decomposition of organic matter and nutrient cycling (Marque et al., 2014). Microbial diversity is an essential part of the soil microbial community (Bender et al., 2016). High microbial diversity enhances soil ecosystem services and tolerance to disturbances such as land use change, seasonality and fertilizer application (Griffiths and Philippot 2013). A decrease in diversity would lead to potential loss of soil functions, reducing the systems stability (Trivedi et al., 2016). Thus, soil microbes should be diverse to ensure sustainable provision of ecosystem services. In agriculture, soil disturbances are common and may be caused by management practices such as land use and fertilizer application (Li et al., 2002). Soil disturbances can also occur naturally through seasonal changes (Luo et al., 2019). Nonetheless, the influences of these factors, i.e., land use, seasonal changes and fertilizer application on soil microbial diversity and related soil functions are still not fully explored.

The study therefore aimed to address the following key question 1) In a regional scale, which is the biggest factor (land use, season or fertilizer) controlling the soil microbiome and 2) Is it possible identify the key microbes and functions impacted by each factor? We therefore conducted
research on soils from cropland and grassland applied with biogas slurry, mainly made of dairy wastes, during summer and spring.

**Materials and Methods**

**Study Site:** The study site was in Kamishihoro (43°14′N, 143°18′E), Hokkaido, Japan.

**Treatments:** Treatments were two land use regimes; cropland (beet- *Beta vulgaris*-farm) and grassland (four plots with two grass species i.e. timothy- *Phleum pretense* and alfalfa- *Medicago sativa*); two seasons; summer (August to October-2018) and spring (April to June-2018) and two fertilizer treatments; Anaerobic digestate and no treatment control. During the experimental period spring (April to June) had average temperature of 10.6°C and cumulative rainfall of 252 mm, while summer (August to October) had average temperature of 14°C and cumulative rainfall of 474 mm.

**DNA extraction and sequencing:** Soil DNA was extracted by phenol-chloroform extraction method (Sagova-Mareckova et al., 2008). First and second Polymerase Chain Reaction (PCR) was conducted targeting V4 region of 16S bacterial gene. DNA sequencing was done with the Ion PGM next generation sequencer.

**Analysis of 16S rRNA based microbial community structure:** Raw sequenced data was processed using QIIME software package version 2018.11(Boylen et al., 2009). Phylogenetic Investigation of Communities by Reconstruction of Unobserved States (PICRUSt) software was used to predict microbial functional attributes (Langille et al., 2013).

**Statistical Analysis:** Statistical analysis of taxonomic and functional profiles (STAMP) software was used to analyze statistical differences between treatments using Welch’s *t*-test (Parks et al., 2014). Taxa and functions that had greater than 1 percent mean proportions were selected for this study.

**Results**

**Effect of imposed treatments on microbial abundance and distribution**

At phylum level, land use had the most effect on changes in relative abundance of soil microbes (Figure 1A), compared to season and fertilizer. Regarding the distribution of soil microbes at family level, land use had the largest effect on soil microbes with grassland having more unique microbial taxa compared to cropland (Figure 1B). The effect of season varied based on land use. In cropland summer had more unique microbes while in grassland spring had more unique microbes.

**Effect of imposed treatments on soil functions**

Land use had the most effect on soil functions with higher functionality recorded in grassland (Fig.2). Although on few functions, season (summer) and fertilizer (organic liquid) had significant effects on function related to metabolism and transcription.
Figure 2: Mean proportions of selected soil related functions that had significant (p < 0.05) differences based on land use treatments.

Discussion [Conclusions/Implications]
Land use had the most effect on microbial abundance, distribution, and soil functions. This may have been caused by differences in management practices between the two land use regimes. Specific to our study, grassland management involved anaerobic digestate application and minimal soil disturbance, while cropland was characterized by relatively larger frequency of tillage, monoculture and the addition of relatively larger amounts of inorganic fertilizers. Our results agree with Bissett et al. (2014) who reported that microbial community differences in cropland and grassland could be related to management practices that influenced soil physical and chemical properties, initiating changes in soil microorganisms’ structure. Our results also indicate that agricultural management practices related to agricultural land use are critical in shaping microbial community structures in agricultural soils, by their influence on microbial abundance, distribution and soil functions. Additionally, higher microbial abundance, distribution and soil functions were recorded in grassland compared to cropland. This may be due to cropland having lower soil pH (5.23) compared to grassland (5.89). Low soil pH in cropland may have been caused by continuous use of ammonium sulphate, an inorganic nitrogen fertilizer (Garvin and Carver, 2003). Msimbira and Smith (2020) found that the ideal pH for most soil microorganisms in agricultural soils was from 5.5 to 6.5, therefore their growth and related functions would be enhanced in grassland (pH 5.89) compared to cropland (pH 5.23) in our study. Our results suggest that management practices that directly or indirectly influence soil pH such as inorganic nitrogen fertilizer additions are important in shaping microbial community structures in agricultural soils.

In cropland, summer had more unique microbes than spring at family level. Our findings can be attributed to higher rainfall experienced during summer (474mm) compared to spring (252mm), that increased soil moisture content and subsequently microbial diversity. Luo et al., (2019) conducted research on the effect of seasonal changes (summer, spring and autumn) on soil microbial diversity in agricultural soils. Based on their results, summer recorded higher diversity compared to spring, due to more rainfall during summer in agreement with our findings. However, in grassland, spring had more unique microbes at family level than summer. This may have been due to higher pH in spring (5.98) compared to summer (5.8) that may have encouraged microbial growth (Msimbira and Smith 2020).

These results show the importance of land use and seasonal changes on soil microorganisms and the resultant provision of related soil functions within the agricultural environment. The study should provide more insight on the effect of combined effects of land use and seasonal treatments on specific soil microorganisms and related functions within the agricultural system at a regional level. Additionally, the study should contribute towards development of sustainable best management practices within the agricultural environment, that will ensure the continued provision of microbial ecosystem services.
Acknowledgements
This work was supported by the MEXT Scholarship grant number 180782.

References


Soil carbon stocks are stable under New Zealand hill country pastures with contrasting phosphorus and sheep stocking regimes

Vibart, R*.; Mackay, A.D.; McKenzie, C.; Devantier, B.; Costall, D.; Noakes, E.; Bilotto, F.
AgResearch, Grasslands Research Centre, Private Bag 11008, Palmerston North 4442, New Zealand.
*Corresponding author: Ronaldo Vibart. E-mail: Ronaldo.vibart@agresearch.co.nz

Key words: soil carbon stocks; pastures; phosphorus fertiliser; sheep grazing; long-term experiment.

Abstract
A temporal and spatial assessment is required to quantify the effects of nutrient inputs and varying grazing management regimes on soil organic carbon (SOC) stocks under grazed pastures in complex landscapes. We examined SOC stocks under permanent pastures in three farmlets under a range of different annual phosphorus (P) fertiliser and associated sheep stocking regimes. The farmlets examined had either no annual P applied (NF), 125 kg single superphosphate (SSP) ha\(^{-1}\) (LF), or 375 kg SSP ha\(^{-1}\) (HF) on an annual basis since 1980. Soils were sampled to three depths (0-75, 75-150, 150-300 mm) in 2003 and 2020, and to the two upper depths in 2014. Each farmlet included three slope classes [low slope (LS), medium slope (MS), high slope (HS)], on three different aspect locations [east (E), southwest (SW), northwest (NW)]. Although a trend \((P = 0.07)\) was observed for greater SOC stocks in the upper depth of the HF farmlet (34.0 Mg C ha\(^{-1}\)) compared with the other two farmlets (31.6 Mg C ha\(^{-1}\)), this trend was discontinued in deeper layers. Accumulated SOC stocks (0-300 mm) were 111.1 (NF), 109.8 (LF) and 111.5 (HF) Mg C ha\(^{-1}\). Soil samples collected on HS resulted in higher soil bulk densities (BD) and carbon-to-nitrogen (C:N) ratios, and lower C concentration and SOC stocks, compared with samples collected on the other two slope classes. Soil samples collected on the NW-facing slopes resulted in higher BD, and lower C concentration and SOC stocks, compared with samples collected on the other two aspect locations. Under the current conditions, contrasting P fertiliser and sheep stocking regimes had minimal effects on SOC stocks. In contrast, topographic features had major effects on SOC stocks, and need to be considered in soil sampling protocols that monitor soil organic carbon stocks over space and time.

Introduction
Studies on long-term phosphorus (P) fertilisation (and associated effects on pasture production and livestock carrying capacity) and soil organic C (SOC) stocks under permanent pastures have shown contrasting results (Condron et al., 2012; Schipper et al., 2013; Young et al., 2016; Coonan et al., 2019; Mackay et al., 2021). A higher sustained P input (and corresponding pasture production) resulted in higher long-term soil C sequestration compared with a no P system (Coonan et al., 2019). In contrast, despite higher annual net primary production (1.9 to 3.6 Mg C ha\(^{-1}\)) from a high- compared with a low-fertility system (the latter with about half the rate of a P-based fertiliser applied over a twenty-year period), soil C stocks were similar (Young et al., 2016). Other than inferred varying C turnover rates, the reasons behind these outcomes are often poorly understood (McSherry and Ritchie 2013).

Previously, Lambert et al., (2000) reported similar SOC stocks in repeatedly sampled pastoral soils under varying P fertiliser regimes (and associated sheep stocking rates) to a depth of 75 mm from 1972 to 1987, at the Ballantrae long-term P fertiliser and sheep grazing study (1972-present). Adding the latter findings to more recent measures from three of the original 10 farmlets, provided a time series (1980-2014) that supports the view that soil C stocks are relatively stable under permanent pastures managed under those conditions (Mackay et al., 2021). The objective of this study was to update (and potentially extend) this view; we examined the effect of long-term contrasting P fertiliser and sheep stocking regimes (herein farmlet effects) and topographical features on SOC stocks under a topographically diverse grassland that is representative of New Zealand’s North Island grazing hill country.
Materials and Methods

The study was conducted at AgResearch’s Ballantrae Hill Country Research Station, in Southern Hawke’s Bay (40.8180° S; 175.8500° E). The Research Station is 300 m.a.s.l. with an average air temperature of 12.8°C and an annual rainfall of 1270 mm. Soils are classified as Brown and Pallic soils (Hewitt, 1998) (Andic Distrochrepts, Typic Distrochrepts and Typic Eutrochrepts in the USDA Classification).

The three self-contained experimental farmlets examined in this study have been under different single superphosphate (SSP; approximately 9% P, 11% S) fertiliser regimes and grazing sheep stocking rates since 1975. Prior to 1975, SSP was applied to the whole site at a rate of 250 kg ha⁻¹ in 1973 and again in 1974. We sampled three farmlets (Mackay et al., 2021): NF (9.7 ha) = no annual P applied, LF (8.1 ha) = 125 kg SSP ha⁻¹ and HF (6.8 ha) = 375 kg SSP ha⁻¹, on an annual basis since 1980. On each of the three farmlets, soils were sampled to a 300-mm depth (0-75, 75-150 and 150-300 mm) in 2003 and in 2020, and to a 150-mm depth (0-75, 75-150 mm) in 2014, as described in Mackay et al., (2021). Farmlets include three slope gradient ranges, herein referred to as slope classes [low slope (LS; 1-12°), medium slope (MS; 13-25°), and high slope class (HS; >25°)], on three different aspect locations grouped relative to the true north [east (E; 35-155°), southwest (SW; 275-355°), and northwest (NW: 155-275°)].

Breeding ewes have been rotationally grazing the farmlets since 1975. Prior to 1975, these farmlets had been carrying about 6.0 stock units (SU) ha⁻¹ (1 SU is defined as a 55-kg breeding-ewes-plus-single lamb consuming 550 kg dry matter (DM) per year). Farmlets were stocked to maintain a similar grazing pressure across farmlets (i.e., similar SU per unit of pasture production). Mean annual stocking rates over the period 1980 – 2014 were 6.9 (NF), 9.8 (LF), and 15.9 (HF) SU ha⁻¹. Corresponding estimates of annual pasture production during the 2015 - 2016 season were 6917, 9708 and 11289 kg DM ha⁻¹ (Mackay and Costall 2016). The effect of farmlet, topographical feature (slope class and aspect location) and sampling year (and their multiple interactions) on soil BD, N and C concentration, C:N ratio, and C stocks were subject to analysis of variance according to a split-split-plot design (Mackay et al., 2021).

Results

Soil organic carbon stocks – Year and farmlet effects

Year of sampling had a significant effect on all soil characteristics leading to SOC stock estimates in the upper depth (0-75 mm), and affected BD and SOC stocks in the following soil depth layer (75-150 mm) (Table 1). Estimates of SOC stocks decreased ($P = 0.02$) from 2003 (32.8 Mg ha⁻¹) to 2014 (31.4 Mg ha⁻¹), but the former were similar to those in 2020 (33.0 Mg ha⁻¹) in the upper soil depth (0-75 mm). Accumulated SOC stocks (0-150 mm and 0-300 mm) were not affected by year of sampling (Table 1). Farmlets had minimal effects on soil characteristics (Table 1). A year-by-farmlet interaction trend on SOC stocks for the upper depth ($P = 0.07$) was most likely associated with numerical differences in SOC stocks in 2003 and 2020, but not in 2014. This trend was not seen in the deeper (75-150 and 150-300 mm) and cumulative (0-150 and 0-300 mm) soil layers (Table 1).

Soil organic carbon stocks – Slope and aspect effects

Slope class had a strong influence on all soil characteristics leading to SOC stock estimates as most variables differed ($P < 0.05$) between the three slope classes at all soil depths (Table 1). Overall, soil samples collected on the steepest slope class (>25°) resulted in lower SOC stocks at all soil depths, compared with samples collected at the other two slope classes (Table 1). Except for C:N ratios and SOC stocks in the upper depth, aspect location had a strong influence on soil characteristics as most variables differed ($P < 0.05$) between the three aspect locations at all soil depths (Table 1). Overall, soil samples collected on the NW-facing slopes resulted in higher BD, and lower N and C concentration, and SOC stocks at all soil depths, compared with samples collected at the other two aspect locations (Table 1).

Discussion [Conclusions/Implications]

The farmlet without P fertiliser for the last 40 years prior to 2020 (NF) represents a low fertility (Olsen P = 3.4 µg ml⁻¹; 0-75 mm), extensive temperate pastoral livestock system carrying about 6 SU ha⁻¹ with pastures dominated by low fertility grasses and few legumes. In sharp contrast, the farmlet that received P fertiliser inputs above annual maintenance requirements since 1975 (HF) represents a high fertility soil (Olsen P = 52 µg ml⁻¹) intensive hill land livestock system (16 SU ha⁻¹).

Despite ongoing divergence in pasture growth, pasture composition and livestock performance (Lambert et al., 2014) and in chemical and biological characteristics of the soils (Lambert et al., 2000; Parfitt et al., 2010; Schon et al., 2019)
the contrasting management regimes (farmlets) had a minimal influence on SOC stocks. These findings seem to contradict those of a review by Conant et al., (2001) that reported that both fertiliser and improved grazing management tend to increase SOC stocks. However, increases in annual rates of C sequestration from changes in grazing management and fertilisation reported by Conant et al., (2001) were minimal compared with other management practices such as conversion from cultivation, introduction of earthworms and irrigation.

Table 1: The effect of year of sampling, farmlet (P fertiliser and associated sheep stocking rate) and topographical feature (slope class and aspect location), on soil bulk density (BD; Mg m⁻³), nitrogen (N) and carbon (C) concentration (%), and C stocks (Mg C ha⁻¹) at the Ballantrae Hill Country Research Station.

<table>
<thead>
<tr>
<th>Variables by soil depth</th>
<th>Year (Y)</th>
<th>Farmlet (F)</th>
<th>Slope (S)</th>
<th>Aspect (A)</th>
<th>s.e.m²</th>
<th>s.e.m⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-75 mm</td>
<td>2003</td>
<td>2014</td>
<td>2020</td>
<td>NF</td>
<td>LF</td>
<td>HF</td>
</tr>
<tr>
<td>BD (Mg m⁻³)</td>
<td>0.79a²</td>
<td>0.87b³</td>
<td>0.89b³</td>
<td>0.86</td>
<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>C (%)</td>
<td>5.62a⁵</td>
<td>4.92a⁵</td>
<td>5.10a⁵</td>
<td>5.14</td>
<td>5.10</td>
<td>5.40</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.44a⁷</td>
<td>0.40b⁷</td>
<td>0.39b⁷</td>
<td>0.40</td>
<td>0.40</td>
<td>0.44</td>
</tr>
<tr>
<td>C stocks (Mg ha⁻¹)</td>
<td>32.8a⁵</td>
<td>31.4a⁵</td>
<td>33.0a⁵</td>
<td>31.6</td>
<td>31.7</td>
<td>34.0</td>
</tr>
<tr>
<td>75-150 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BD (Mg m⁻³)</td>
<td>0.97a⁵</td>
<td>1.00a⁶</td>
<td>1.06a⁶</td>
<td>1.03</td>
<td>1.06</td>
<td>1.01</td>
</tr>
<tr>
<td>C (%)</td>
<td>3.91a⁸</td>
<td>3.97a⁹</td>
<td>3.85</td>
<td>3.99</td>
<td>3.79</td>
<td>3.96</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.31a⁸</td>
<td>0.32a⁸</td>
<td>0.31</td>
<td>0.32</td>
<td>0.30</td>
<td>0.32</td>
</tr>
<tr>
<td>C stocks (Mg ha⁻¹)</td>
<td>28.5a⁸</td>
<td>31.3a⁸</td>
<td>29.9a⁸</td>
<td>30.2</td>
<td>29.7</td>
<td>29.8</td>
</tr>
<tr>
<td>150-300 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BD (Mg m⁻³)</td>
<td>1.20a⁸</td>
<td>-</td>
<td>1.16</td>
<td>1.19</td>
<td>1.19</td>
<td>1.17</td>
</tr>
<tr>
<td>C (%)</td>
<td>2.76a⁸</td>
<td>-</td>
<td>2.81</td>
<td>2.88</td>
<td>2.75</td>
<td>2.73</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.22a⁸</td>
<td>-</td>
<td>0.23</td>
<td>0.24</td>
<td>0.22</td>
<td>0.21</td>
</tr>
<tr>
<td>C stocks (Mg ha⁻¹)</td>
<td>49.7a⁸</td>
<td>-</td>
<td>47.7</td>
<td>50.2</td>
<td>48.6</td>
<td>47.3</td>
</tr>
<tr>
<td>300-450 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BD (Mg m⁻³)</td>
<td>1.110</td>
<td>-</td>
<td>1.10</td>
<td>1.11</td>
<td>1.098</td>
<td>1.115</td>
</tr>
<tr>
<td>C (%)</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N (%)</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


a-b-c Within each main factor (Y, F, S, A) and soil variable, numbers with different superscripts differ (P ≤ 0.05).
Findings from our study, however, are consistent with those of Lambert et al., (2000) who reported that varying P fertiliser inputs and sheep grazing regimes did not influence SOC stocks in the 0-75 mm soil depth on the LF and HF farmlets. Our findings are also consistent with those of Condron et al., (2012), who reported that despite higher annual pasture yields (i.e., 2.4- to 2.8-fold higher for the P fertiliser treatments compared with no P applied), the concentrations and amounts of organic C were similar across treatments. The absence of a significant accumulation of soil organic C in response to increased production was attributed to accelerated decomposition of organic matter inputs associated with a combination of improved pasture quality and increased earthworm activity (Condron et al., 2012).

Saggar et al., (1997) examined the partitioning and translocation of photosynthetically fixed C\textsuperscript{14} in a grazed hill pasture, and showed that while more of the C assimilated in a low fertility (LF) pasture was translocated below ground, a high fertility pasture (HF) still assimilated more total C and translocated more C below ground to roots. The increased C translocation below ground in a HF system did not translate into increased soil C stocks, and this points to systems where the total C pool is highly regulated. Greater earthworm biomass and diversity (Schon et al., 2019) and a shift from fungal to bacterial pathways in soil microbial and microfaunal processes (Parfitt et al., 2010) are present in the HF farmlet, suggesting a greater capacity for turnover of plant shoot and root biomass, and animal faeces. Based on the findings of our study and earlier findings by Lambert et al., (2000) and Schipper et al., (2011), the soil organic matter pool size remains relatively stable over time under permanent pasture under a diversity of pasture management regimes that would embrace the range of soil fertility and sheep stocking rates found in most hill country systems.

Sequestering of organic carbon C in soil offers an option for offsetting C atmospheric emissions. We examined soil C accumulation under a long-term P application and sheep-stocking regime grazing experiment. The hill country experiment has been running since 1975, with three distinct farmlets that received either no P fertiliser, an intermediate amount or an amount that exceeds annual maintenance. While farmlet regime had a minimal impact on soil C accumulation, slopes and aspects had a substantial impact and need to be considered in the design of soil sampling regimes that monitor soil organic carbon over space and time.

Acknowledgements

All the science, technical and farm and service staff that have been involved with the long-term study at the AgResearch Hill Country Research Station, Ballantrae since its establishment. The authors would like to recognise funding from the AgResearch Strategic Science Investment Fund.

References


THEME 1. RANGE /GRASSLAND ECOLOGY

Topic: Community Composition and Ecological Drivers
Climate variability in the Woodbush Granite Grasslands of South Africa: Effects on grassland diversity

Muller, M1; Siebert, F1; Linstädter, A2; Thompson, D.I3,4; Siebert, S.J1.

1 Unit for Environmental Sciences and Management, North-West University, Potchefstroom 2520, South Africa; 2 Biodiversity Research/Systematic Botany, University of Potsdam, Potsdam, Germany; 3 South African Environmental Observation Network (SAEON), Ndlovu Node, Phalaborwa, South Africa; 4 School of Geography, Archaeology & Environmental Studies, University of the Witwatersrand, Johannesburg, 2050, South Africa.

Key words: grassland diversity; drought; fragmented pristine grassland; gains; losses; abundance; occurrence

Abstract

South African old-growth grasslands are hyper-diverse ecosystems which evolved under naturally occurring rainfall variability. It is predicted that future precipitation patterns will become more variable, which could lead to increased frequencies of extreme and prolonged drought events. This study aimed to investigate the effects of climate variability on plant diversity of the fragmented pristine, mistbelt grasslands of the Woodbush Granite Grasslands (WGG) at Haenertsburg, South Africa. It has been reported that species composition has changed substantially in this area, as disturbance-tolerant species enter these systems or existing competitor species become more dominant. A Temporal Beta-diversity Index (TBI) was used to determine the gains and losses in taxonomic and functional diversity, and of endemic and threatened species since 2009. Results show that there was a gain in species from before (2009) to onset of drought (2015) and a loss in species from the onset of the drought (2015) to after the drought (2019), while the overall effect of the drought on species occurrence from 2009 to 2019 was non-significant suggesting ecosystem resilience to drought.

Introduction

The old-growth grasslands of South Africa evolved in the presence of the endogenous disturbances, such as lightning-ignited fires, rainfall variability and large mammalian herbivory (Buisson et al., 2019; Koerner and Collins 2014). For this reason, grassland ecosystems are tolerant and to some extent dependent upon these natural disturbances (Buisson et al., 2019).

Drought is a natural occurring phenomenon characterized by changes in precipitation, soil moisture, groundwater and streamflow (Botai et al., 2019). During November of 2015 to April of 2016, most parts of South Africa experienced a severe drought during the rainy season (Yuan et al., 2018). This seasonal drought was intensified by heat waves and a soil moisture deficit (Yuan et al., 2018).

It is expected that drought events may become more frequent in years to come (IPCC 2012, Hoffman et al., 2019) with associated warmer temperatures and declines in annual rainfall (Bodner and Robles 2017). Studying the impact of drought on grasslands has gained urgency as there is a need to understand how droughts will impact the sustainable management of grasslands now and in the future (Bodner and Robles 2017). Therefore, an improved understanding of the floristic and functional diversity is necessary to understand the community and functional shifts related to climate change.

The objectives of this study were to assess floristic changes related to rainfall variability in Woodbush Granite Grassland (WGG) through the application of the Temporal Beta-diversity Index (TBI) with a particular focus on taxonomic diversity, and endemic and threatened species.

Methods and Study Site

A diverse, but threatened grassland type in South Africa, the WGG, was selected to test the effects of rainfall variability on grassland diversity and function. The WGG occurs around Haenertsburg...
within the Mesic Highveld Grassland Bioregion of the Grassland Biome and forms part of the Wolkberg Centre of Endemism (Van Wyk and Smith 2001). This grassland type is listed as a Critically Endangered ecosystem since only about ~6% is still in a natural state (Mucina and Rutherford 2006). The largest remaining fragment of WGG is only 192 ha (Dzerefos et al., 2017), which is surrounded by multiple land-use types. The WGG borders the Sour Bushveld vegetation of the Savanna Biome to the east (Mucina and Rutherford 2006), which is anticipated to expand and encroach into WGG as a result of climate change (i.e. drier, warmer climate and increased atmospheric CO₂) (Bond and Midgley 2000; Bond and Midgley 2001; Clarke et al., 2013). Embedded in the grassland are patches of Northern Mistbelt Forest. Since the WGG is critically threatened and the remaining fragments very small, the conservation value of the area is high.

The South African Environmental Observation Network (SAEON) has erected 40 permanent annual burn vegetation monitoring plots in the WGG. These plots have been monitored since 2009, and baseline vegetation data have been collected to compile a floristic dataset. The sampling and data collection conforms to the SAEON sampling protocol for long-term grassland monitoring, i.e., permanent plots have a size of 4 x 4 m, and are divided into 16 smaller subplots of 1 m² each. In the four corner subplots of the 16 m² plot, the percentage aerial cover of grass, forb and woody species was recorded. Thus, a total of 160 subplots was sampled during each sampling event. Sampling was done in February, i.e., at the time of peak standing crop. Sampling was done in the years 2009, 2015 and 2019. During this observation period, a severe drought occurred in 2015. The tree sampling events thus represent pre-drought (2009), drought (2015) and post-drought conditions (2019).

Non-Metric Multi-Dimensional Scaling (NMDS) analysis in Primer (2007) explored changes in species composition between sampling events 2009, 2015 and 2019. To determine whether significant differences in plant assemblages exist over time, Permutational Multivariate Analysis of Variance (PERMANOVA) was performed using species abundance data. Analyses were conducted with 999 permutations using Bray-Curtis similarity and type III sums of squares after a square-root transformation of species data to reduce the influence of common species. Single factor ANOVA tests were applied to test for significant differences between 2009, 2015 and 2019 for selected diversity measures.

According to Legendre (2019), aerial cover data can be treated as species abundances in the Temporal Beta-diversity Index (TBI) test. The TBI calculations were implemented in the TBLR function available in the package adespatial of the R software (version 4.0.2). The percentage difference (%diff), also known as the Bray-Curtis dissimilarity index, was used as it contains the proxies B and C, which represent the species loss and gain components of dissimilarities (Legendre 2019). B-C plots (Fig. 1) were created with the B/den and C/den statistics as coordinates of points, representing sites. These graphs visually display the relative importance of the loss and gain processes across time. The function paired. krandtest.R was used to identify the species abundances that have changed significantly between T1 and T2 (Legendre 2019).

Results
The aerial cover of 261 species was determined across 160 subplots, which included 45 grass species, 173 forb species and 43 long-lived forb and woody/shrub species. Of these species, 14 were South African endemics (5%), three endangered (1%) and one near threatened. The most prominent families were the Asteraceae (19%), Poaceae (15%) and Fabaceae (13%).

The results from the NMDS revealed separate clusters for the three years, 2009, 2015 and 2019 (Fig. 1). These annual clusters were verified by PERMANOVA (df = 2, pseudo-F = 16,017, p = 0,001), which indicated a significant difference in floristic composition between years. The species that contributed most to these changes from 2009 to 2019 are the grasses Cymbopogon nardus (L.) Rendle, Loudetia simplex (Nees) C.E.Hubb., Setaria sphacelata (Schumach.) Moss and Themeda triandra Forssk., and the forbs Acalypha peduncularis E.Mey. ex Meisn., Berkheya setifera DC. and Helichrysum nudifolium (L.) Less.

![Figure 1: Non-Metric Multidimensional Scaling (NMDS) ordination for 2009 (pre-drought), 2015 (onset of drought) and 2019 (post-drought) plots with species abundance data.](image)
Species richness and diversity was expected to be affected by the drought conditions of 2015. Single factor ANOVA tests revealed significant changes for all diversity measures (i.e., J', H' and S) for the three years (p<0.001, Table 1).

Table 1: Mean values (±SD) of selected diversity measures for pre-drought (2009), at the onset of drought (2015) and post-drought (2019) conditions. Significance was set at p < 0.05.

<table>
<thead>
<tr>
<th>Measure</th>
<th>2009</th>
<th>2015</th>
<th>2019</th>
<th>df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pielou's evenness</td>
<td>0,77 ± 0,007</td>
<td>0,77 ± 0,005</td>
<td>0,77 ± 0,005</td>
<td>2</td>
<td>7,42</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Shannon Diversity</td>
<td>2,182 ± 0,144</td>
<td>2,404 ± 0,085</td>
<td>2,404 ± 0,085</td>
<td>2</td>
<td>23,15</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total species (S)</td>
<td>17,3 ± 21,0</td>
<td>21,0 ± 17,5</td>
<td>17,5 ± 12,8</td>
<td>2</td>
<td>39,09</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

In the B-C plots (Figure 2), the diagonal green line (slope = 1) goes through the origin, and represents the theoretical positions of sites where the gain would be equal to the loss (Legendre 2019). The red line, parallel to the green line, passes through the centroid of all points (Legendre 2019). When the red line is below the green line, it indicates that species loss dominated across the sites, with the opposite being true if the red line is above (Legendre 2019). Furthermore, points found toward the upper-right corner represent higher temporal beta diversity than points found toward the lower-left corner (Legendre 2019).

The function `tpaired.krandtest.R` revealed the following: Threatened and endemic species that significantly contributed to the changes observed in Figure 1 include the near threatened species *Merwilla plumbea* (Lindl.) Speta which significantly increased in occurrence from 2009 to 2015 and significantly decreased in occurrence from 2015 to 2019; the endemic species *Alepidea peduncularis* A.Rich. which significantly decreased in occurrence from 2009 to 2019; *Pygmaeothamnus chamaedendrum* (Kuntze) Robyns var. *chamaedendrum* which significantly increased in occurrence from 2009 to 2015; *Senecio pentactinus* Klatt which significantly decreased in occurrence from 2009 to 2019; and *Argyrolobium transvaalense* Schinz which significantly decreased in occurrence from 2015 to 2019.

- Overall significant gain of species
- Total significant species = 68
- Significant grass species = 20
- Significant forb species = 41
- Significant woody species = 7

- Overall significant loss in species
- Total significant species = 53
- Significant grass species = 15
- Significant forb species = 33
- Significant woody species = 5

- Overall non-significant gain in species
- Total significant species = 66
- Significant grass species = 19
- Significant forb species = 40
- Significant woody species = 7
Overall significant gain of species abundances (cover)
- Total significant species = 73
- Significant grass species = 20
- Significant forb species = 45
- Significant woody species = 8

Overall significant loss of species abundances (cover)
- Total significant species = 59
- Significant grass species = 14
- Significant forb species = 39
- Significant woody species = 6

Discussion
We assumed that a severe drought would trigger a substantial loss of plant diversity. However, our results do not support this assumption. There were significant differences (p<0.001) between years for all diversity measures (J', H' and S; Table 1) when 2009 was compared to 2015, and 2015 to 2019. However, no significant differences were observed when the years 2009 (pre-drought) and 2019 (post-drought) were compared (p>0.001). This indicates that the WGG system is quite resilient, and in accordance with a growing body of work that supports the idea that biodiversity promotes ecosystem functioning and stability (Mori et al., 2013).

The TBI analysis for species occurrences supports the idea that the WGG system is resilient to drought, as there was an overall gain in species from 2009 to 2019, even though it was not significant. This means the gains and losses of species seem to compensate each other, as the mean number of species (Table 1) was similar pre- and post-drought. It has been observed that the effect of drought alone on grasslands had a minimal impact on plant community structure and composition (Koerner and Collins 2014). The combination of drought with other disturbances, such as fire and grazing, could have a more significant effect on grassland communities as observed for savanna (Siebert et al., 2020).

It was expected that the drought would result in loss of species, but it appears that the drought rather impacted the abundances of species more severely. Even though there was a significant loss in abundance of species from 2009 to 2019, it has been observed that vegetation in southern Africa has either remained stable or has increased in cover and biomass over the course of the 20th century (Hoffman et al., 2019). It is therefore expected that the abundance of species will recover over time to be similar to that experienced before the drought event.

It would appear that the species in the WGG are to some extent drought tolerant, which would be a benefit to the system as grasslands without drought-tolerant species would likely experience major declines in ecosystem functioning during times of drought (Craine et al., 2013). This knowledge could aid our understanding of the distribution of drought tolerant plants in order to better predict future responses and resilience to climate change (Craine et al., 2013).

This study set out to assess the impact of a severe, multiple-year drought event on the floristic diversity of a biodiverse South African grassland.
Unexpectedly, the drought event did not have a strong effect on species occurrence from 2009 to 2019. However, there was a decrease in species cover and slight changes in species composition. Further studies are needed to determine the effect of severe drought events on grasses, forbs and woody species, as it is predicted that woody species will increase in grasslands (Gibson et al., 2018) due to interactions between fire and grazing regimes, rainfall variability and atmospheric CO₂ levels (Archer et al., 2017).

Acknowledgements
Our appreciation to SAEON for the long-term floristic cover data, and to Mightyman Mashele and Tsumbedzo Ramalevha from SAEON for their assistance with field surveys. We acknowledge funding by the German Federal Government (BMBF) through the SPACES initiative (‘SALNet’ project – grant 01LL1802C) and by the National Research Foundation (NRF) of South Africa.

References


Mongolian rangelands have a great potential for natural recovery

Bulgamaa, D.,¹ Sumjidmaa, S.,² Brandon, B.,³ Budbaatar, U.,² Burmaa, D.,⁴ Erdenetsetseg, B⁴

¹Green Gold Animal Health Project, Swiss Agency for Development and Cooperation, Sky Plaza Business Centre, Olympic street 12, Sukhbaatar District, Ulaanbaatar 14210, Mongolia
²Mongolian National Federation of Pasture User Groups; 22-20A, Baga toiruu, Sukhbaatar district, Ulaanbaatar, Mongolia
³United States Department of Agriculture-Agricultural Research Service, Jornada Experimental Range, New Mexico State University, Las Cruces, New Mexico 88003 USA
⁴National Agency for Meteorology and Environmental Monitoring, Juulchiny street - 5, Baga Toiruu-3, Ulaanbaatar 15160, Mongolia
Correspondence: bulgamaa@greengold.mn

Keywords: Mongolia, rangeland, recovery class concept, ecological site groups, resilience

Abstract
Mongolians are aware that rangeland degradation is accelerating due to the combination of unsustainable use and drought events, but the natural recovery of degraded rangeland and timelines for recovery are less well studied. In this paper, we describe the use of “recovery class” concepts in rangeland classification that are being used to evaluate rangeland condition and management impacts across Mongolia. Recovery classes are analogous to degradation classes already used in Mongolia, but are based on ecological site descriptions (ESDs) and provide information about expected recovery rates based on quantitative measurements. While the degradation levels communicate the severity of plant community departure from reference conditions, the recovery classes communicate the management needs and timelines for recovery. According to the national report of Mongolian rangeland health, as of 2015, 65 percent of Mongolian rangelands was altered to some degree. Plant community composition, however, indicates that in more than half of sampled areas, changes to grazing management could result in recovery, or progress toward recovery, within ten years. Fifteen percent of nationwide rangeland health monitoring plots had evidence of recovery within 2 years between 2014-2016 and shifted to a more desirable state of their respective State and Transition models.

Introduction
As one of the few remaining countries with a robust, nomadic pastoral culture supported by extensive natural rangelands, Mongolia is well positioned to offer sustainable, rangeland-based goods and services to its citizens and global consumers who place a premium on sustainable products. In order to create a national assessment of rangeland health and certification of responsible management that incorporates variations in ecological potential across Mongolia, standardized “recovery classes” were developed (Densambuu et al., 2015). The recovery class hypothesizes timelines to recovery of the reference (healthy) state based on vegetation cover and composition data interpreted according to expert knowledge and existing studies when available, captured in state and transition models (Bestelmeyer et al., 2017). For example, the presence of remnant perennial grasses suggests that recovery of a reference state can occur within several years. The recovery classes allow standardized interpretations across multiple state and transition models to allow for reporting and visualization of rangeland restoration needs.

One of the key products produced by the nationwide rangeland health monitoring system is the recovery class map that is used for decision makers and practitioners as an efficient tool to plan appropriate management and interventions.

Materials and methods
Recovery class concept development efforts started with training for core research team on methods to develop ESDs in the US in early 2009, followed by data collection co-occurring with trainings in Mongolia.
Following recommendations adopted by US agencies, inventory of vegetation and soils was conducted at over 600 sites across Mongolia, coupled to workshops aimed at eliciting local knowledge about reference conditions, the presumed causes of vegetation change, and to identify informative sites for inventory. The recovery class concept has 5 levels from a highly productive reference state (I) to an irreversibly degraded level with severely reduced ecosystem service provision (V). Classes in between (II-IV) hypothesize timelines to recovery of the reference state based on vegetation cover and composition data interpreted via state and transition models developed for 23 land classes across Mongolia (Densambuu et al., 2018b). Depending on the cover of key species, soil surface characteristics, and grazing management natural recovery rates vary from 1-3 (Class I), 3-5 (Class II), 5-10 (Class III), and > 10 years (Class IV) or it is unlikely that the reference state can be recovered over any timeframe (Class V; often regarded as true desertification).

Results
According to the latest national report on Mongolian rangeland health (Densambuu et al., 2018a) and the recovery class map for Mongolian rangelands, 43 % of 1516 monitoring sites were in Class I (healthy reference state); 29 % in Class II; 16 % in Class III; and 12 % in Class IV. Thus, a majority of sites were altered from a reference state, but all have potential for natural recovery. Most monitoring sites in High mountainous and Desert ecological zones are at reference condition or could recover rapidly (Class I). A high percentage of sites requiring more than 3 years of management for recovery (Class II-IV) were observed in forest steppe, steppe and desert steppe zones.

Comparing the recovery classes of 2014 and 2016, 51% of the monitoring sites have not changed over the past 2 years with respect to the expected timeline to recovery, while 15% of sites are on a path to more rapid recovery and 34% will now take even longer to recover.

Sandy loam soils in steppe and desert steppe zones respond quickly to favorable conditions because i) sandy loam soils in Mongolia generally have a high amount of organic matter in the surface horizon that supports recovery in years with average to above average precipitation amounts; ii) most sites have a relatively rich seedbank to promote plant recruitment once the grazing pressure is moderated; iii) herders in this area move large distances, especially in dry years, that allows for some rest from grazing. The potential recovery rate slows in areas that have undergone transitions from perennial grasses with strong tap roots to rhizomatous species such as sedges (Carex) and subshrubs (Artemisia). A high cover of these unpalatable species produces low quality litter that slows down nutrient cycling and recovery of productivity (Ritchie et al., 1998).

Figure 1: a) State and Transition model for Stipa krylovii-Grass with Caragana steppe rangeland; b) Perennial grass dynamics under contrasting management indicate the potential rate of recovery from State III to State I.
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

Stipa krylovii-Grass with Caragana steppe rangeland (Figure 1a) is one of the most common rangeland types on deep sandy alluvial plain in Mongolia that has a high potential for natural recovery (Chognii 2001). As a result of rotational grazing management the heavily degraded Stipa krylovii-Grass with Caragana steppe rangeland, which was dominated by Carex and Artemisia spp, has recovered and shifted from the alternative state 3 (Dominant species changed state) to the grass-dominated healthy state 1 in 3 years (2013-2016) (Fig 1b.). Cover of perennial grasses, mainly Stipa spp, has increased by 5.5 times in 3 years and stabilized.

Discussion and Conclusion

The recovery class concept is an important tool for interpreting the current state of rangeland health and for planning the appropriate management and restoration measures. Government agencies such as Agency for Land Management, Geodesy and Cartography and National Agency for Meteorology and Environmental Monitoring have adopted this concept for interpretation of vegetation monitoring data.

The timing required for natural recovery varies depending on the ecological site. Sites with sandy and sandy loam soil are more sensitive to continuous grazing but respond to grazing management changes very well, especially when combined with sufficient precipitation. The pathway to recovery also varies; in most cases communities shift to adjacent, better condition states following the proposed timelines but sometimes recovery to a reference state can be rapid. Recovery of Tripteris sinuata DC., for example, was significantly slower in plots with a history of heavy grazing that endured ongoing grazing by sheep, compared with plots with a history of moderate grazing and the equivalent treatment. This is probably because once the vegetation is in a state of low biomass, the grazing pressure needed to subsequently suppress vegetation re-growth is far lower than that needed to cause the collapse in the first place (Colleen et al., 2010).

Restoring the full suite of palatable species over practical management timeframes will require more complex interventions such as reseeding or selective clearing (Colleen et al., 2010).

Nonetheless, even when most grasses are lost and communities are dominated by rhizomatous species and forbs, there are ample opportunities for changes in management and policy that support the recovery of rangelands in Mongolia because soils are seldom severely or permanently degraded (at least in our monitoring record). It is important, however, to act decisively and promptly before recovery opportunities are lost.

Acknowledgements

We are thankful to Swiss Agency for Development and Cooperation (SDC) in Mongolia for supporting the all studies, development of related concepts and capacity development of all professional Institutes and agencies for new methodologies and USDA experts for providing the technical consultancy.

References


Germinable soil seed bank of *Bothriochloa macra* dominated pasture in south-eastern Australia

Mitchell, M.L.¹; Virgona, J.M. ²; Durling, A¹; Dempsey, F.W.¹

¹Agriculture Victoria, Rutherglen Centre, 124 Chiltern Valley Road, Rutherglen, Vic 3685, Australia; ²Graminus Consulting P/L, PO Box 5201, Wagga Wagga, NSW 2650, Australia.

Key words: grazing management; botanical composition; perennial; native grass; pasture

Abstract

In native pastures, soil seed banks play an important role in conserving the genetic material in a plant population, influencing community structure and providing protection against adverse climatic conditions. One important native grass is *Bothriochloa macra* (Steud.) S.T.Blake (Red grass, Red-leg grass). This grass is a C₄ indigenous perennial grass that is commonly found in native pastures in the high rainfall zone of south-eastern Australia.

At Tarrawingee, NE Victoria, (36°25´S, 146°31´E) and Wymah, southern NSW, (35°58´S, 147°11´E), Australia, two sites that had *Bothriochloa macra* as the dominant native grass were sampled. Three hundred cores (50 mm diameter and 50 mm depth) were collected from each site and bulked in May 2005. The soil samples were spread evenly over seed raising flats and maintained in a glasshouse, under natural light and modified day/night temperatures. The samples were kept moist for periods of between 35 and 70 d. During each census, germinants were identified to the following functional groups (*B. macra*, broadleaf, grass and legume) and removed. At the end of each cycle remaining seedlings were counted and water withheld. The dry soil samples were then thoroughly mixed and re-watered to initiate another cohort of germination. This cycle was repeated five times over a nine-month period.

These counts showed that *B. macra* only represented a very low proportion of the soil seed bank (1.1 to 3.4% of total germinants), with the soil seed bank dominated by annual species. Fifty-eight different species germinated from the soil seed bank, with 83% of all seeds germinating in the first two cycles. The soil seed bank of these *B. macra* pastures possessed characteristics typical of most soil seed banks, including poor correlation with the standing vegetation, domination by one or two species and low representation of perennial species.

Introduction

Grazed pastures dominated by native grasses occupy around 22% of agricultural land in the high rainfall zone of south-eastern Australia (Hill et al., 1999). *Bothriochloa macra* (Steud.) S.T.Blake (Red grass, Red-leg grass, hereafter *Bothriochloa*) is an indigenous species that is commonly found in these pastures (Garden et al., 2001) and is a low growing C₄ perennial (Simon 1990). In many hilly parts of the landscape native grass pastures offer the only sustainable options for grazing, maintaining perennial ground cover and reducing rates of land degradation (Simpson and Langford 1996). The relative abundance of native grasses within these pastures is critical for landscape function with respect to natural resource management reducing deep drainage and maintaining ground cover (Virgona et al., 2003).

Soil seed banks play an important role in plant population dynamics and community structure (Fenner 1985; Teo-Sherrell et al., 1996). They serve as pools of genetic material that act as a population buffer against adverse climatic conditions. Soil seed banks can be composed of seed that is produced in that area, or seed that has come from elsewhere via wind, water or animals (Harper 1977). Seed in the soil seed bank is continually added to by seed rain and thus represents past and present vegetation of the area and surrounding areas (Harper 1977). Seed can be lost from the soil seed bank by predation, old age – loss of viability, soil pathogens, fungal attack, decay or germination.

Soil seed banks are one component in the population biology of a species. Germination,
emergence and survival of a species are key life-history stages that ensure persistence of plant populations (Clarke and Davison 2004). There is a paucity of published information on either the size or composition of germinable soil seed banks in native pasture communities in the high rainfall zone (annual average rainfall > 550 mm) of southern Australia. Quantifying the regeneration potential of the soil seed bank is an important aspect in developing management strategies for sustainable land use (McIvor and Gardener 1994). The aim of this experiment was to improve our understanding of the quantities of germinable Bothriochloa seed that are present in the soil.

Materials and Methods
The experiment was conducted on two native pasture sites. The Tarrawingee site in NE Victoria (36°25´S, 146°31´E) had an annual average rainfall of 643 mm, soil pH (CaCl₂) of 6.4 and Bothriochloa 24% of above ground biomass. The Wymah site in southern NSW (35°58´S, 147°11´E) had an annual average rainfall of 751 mm, soil pH (CaCl₂) of 4.9 and Bothriochloa 40% of above ground biomass.

Samples were collected at Tarrawingee on 23 May 2005 and at Wymah on 18 May 2005. From each site, three hundred cores (50 mm diameter and 50 mm depth) were collected and bulked. Bulked soil samples were dried at 40°C for 48 h and sieved to remove gravel and remaining plant material. The samples were then sieved through a coarse (4 mm) and fine (2.5 mm) sieve (Ter Heerdt et al., 1996). Each sample was divided into four and placed on germination trays, which were randomly allocated to four replicated blocks in a randomised complete block design to account for variation in temperature and light within the glasshouse.

Soil samples were spread evenly over seed-raising flats containing sand and peat mix (2:1) with a layer of vermiculite. The soil samples were maintained in a glasshouse at the Agriculture Victoria, Rutherglen, under natural light and modified day and night temperatures, 14 to 42°C in summer and 9 to 31°C in winter. To ensure that the soil was kept moist, black plastic was topped with a layer of capillary mat (geotextile fabric), and then permeable weed mat and the trays were placed on a layer of vermiculite. Plastic tubes with holes were placed down three sides of the table to keep the weed mat moist. An automatic tap timer was used to apply water for 10 minutes every 24 h.

The samples were kept moist for periods of between 35 and 70 days from August 2005 to June 2006. Germinated seedlings were removed, identified and classified into the following functional groups: native grass, broadleaf species, grasses (both annual and perennial) and legumes. At the end of each germination cycle, remaining seedlings were counted, and water withheld. The dry soil samples were thoroughly mixed and re-watered to initiate another cohort of germination. There were five cycles of germination.

Soil seed bank seedling counts were analysed using ANOVA within Genstat (Payne et al., 2014). Least significant differences (l.s.d.) are shown at the P = 0.05 level.

Results
Summer rainfall (December 2004, January 2005, February 2005) was above average for both sites, Tarrawingee site 226 mm (LTA 126) and Wymah site 223 mm (LTA 144). Whereas autumn rainfall (March, April, May 2005) was well below average at both sites, Tarrawingee site 18 mm (LTA 147 mm) and Wymah site 34 mm (LTA 171 mm).

The total seed density for Tarrawingee was 737,291 seeds/m² and Wymah was 1,096,646 seeds/m². Fifty-eight different species germinated from the seed bank. Within the first two cycles, 83% of the total seed germinated (Table 1). The germinable soil seed bank was dominated by species in the ‘Other species’ category, with this grouping Juncus L. spp. accounted for 51% of the total soil seed bank.

The majority (87%) of the Bothriochloa germinated in the first cycle at both sites (Table 1). Bothriochloa only represented 2% of the total soil seed bank, with more Bothriochloa germinated from the soil seed bank collected at the Tarrawingee site. Overall, native grasses only represented 3% of the total germinable soil seed bank (Table 2). The soil seed bank at both sites were dominated by introduced species which represented 94% of the individuals to germinate and 79% of total species that germinated.
Table 1: Mean number of seeds germinating (m²) in the soil seed bank for each of the five germination cycles for five species groups for Tarrawingee and Wymah field sites.

<table>
<thead>
<tr>
<th>Cycle number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>1.s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(P = 0.05)</td>
</tr>
<tr>
<td>Tarrawingee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bothriochloa</td>
<td>1,078</td>
<td>151</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>194</td>
</tr>
<tr>
<td>Other native grasses</td>
<td>316</td>
<td>75</td>
<td>42</td>
<td>22</td>
<td>10</td>
<td>176</td>
</tr>
<tr>
<td>Annual broadleaf</td>
<td>2,436</td>
<td>727</td>
<td>126</td>
<td>39</td>
<td>706</td>
<td>907</td>
</tr>
<tr>
<td>Annual grass</td>
<td>720</td>
<td>51</td>
<td>15</td>
<td>37</td>
<td>3</td>
<td>646</td>
</tr>
<tr>
<td>Legumes</td>
<td>289</td>
<td>37</td>
<td>36</td>
<td>66</td>
<td>41</td>
<td>310</td>
</tr>
<tr>
<td>Other species</td>
<td>19,696</td>
<td>4,125</td>
<td>659</td>
<td>674</td>
<td>4,680</td>
<td>4,686</td>
</tr>
<tr>
<td>Wymah</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bothriochloa</td>
<td>526</td>
<td>73</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>194</td>
</tr>
<tr>
<td>Other native grasses</td>
<td>616</td>
<td>183</td>
<td>8</td>
<td>3</td>
<td>34</td>
<td>176</td>
</tr>
<tr>
<td>Annual broadleaf</td>
<td>10,792</td>
<td>979</td>
<td>487</td>
<td>151</td>
<td>567</td>
<td>907</td>
</tr>
<tr>
<td>Annual grass</td>
<td>10,792</td>
<td>979</td>
<td>487</td>
<td>151</td>
<td>567</td>
<td>907</td>
</tr>
<tr>
<td>Legumes</td>
<td>7,470</td>
<td>146</td>
<td>185</td>
<td>755</td>
<td>657</td>
<td>310</td>
</tr>
<tr>
<td>Other species</td>
<td>16,058</td>
<td>3,180</td>
<td>222</td>
<td>256</td>
<td>3,837</td>
<td>4,686</td>
</tr>
</tbody>
</table>

Table 2: General characteristics of soil seed bank of Bothriochloa dominated pastures in southern Australia.

<table>
<thead>
<tr>
<th>Group</th>
<th>Individual/seeds</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td>Annual</td>
<td>47,860</td>
<td>90</td>
</tr>
<tr>
<td>Perennial</td>
<td>5,487</td>
<td>10</td>
</tr>
<tr>
<td>Introduced</td>
<td>49,991</td>
<td>94</td>
</tr>
<tr>
<td>Native</td>
<td>3,356</td>
<td>6</td>
</tr>
<tr>
<td>Monocotyledon</td>
<td>35,369</td>
<td>66</td>
</tr>
<tr>
<td>Dicotyledon</td>
<td>17,978</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>53,347</td>
<td>58</td>
</tr>
</tbody>
</table>
Discussion

The soil seed bank of these Bothriochloa pastures in southern Australia possessed characteristics typical of most soil seed banks, including high spatial variation, poor correlation with the standing vegetation, domination by one or two species and low representation of perennial native grasses. The outstanding feature of the results from this experiment was the small number of Bothriochloa seeds in the germinable soil seed bank. Annual grasses, annual broadleaf species and sedges dominated the soil seed bank of these pastures. These low levels of germinable Bothriochloa seed in the soil seed bank suggest it is likely that there are limited opportunities for seedling recruitment. Bothriochloa seedlings that could germinate would face immense competition from the germination of other species in the soil seed bank.

For the Tarrawingeec site, Bothriochloa germinated in four of the five cycles, whereas at Wymah it germinated in only three cycles. A small proportion (less than 10%) of Bothriochloa seed may have long-term viability or dormancy. Low levels of Bothriochloa seed dormancy and high germination percentages (> 80%) have been previously found (Johnston et al., 1998; Clarke and French 2005; Clarke et al., 2007).

Seasonal conditions clearly influenced the number of Bothriochloa seedlings in the soil seed bank. These samples were collected after a wet summer, where the Bothriochloa produced large quantities of seed. Species not found cannot automatically be presumed to be absent from the soil seed bank, since sampling procedure, such as time of year, and germination procedures may not have been appropriate for all species (Lunt 1997). The sampling intensity used in this experiment was considered sufficient to indicate the general characteristics of the soil seed bank, particularly in terms of life form and origin.

The composition of the soil seed bank did not reflect the above-ground species composition. The general reason for this is that it contained seeds from both the past and present vegetation and species have different seeding capacities and seed viability over time (Harper 1977). This difference between species composition above ground and in the soil seed bank has been found in a range of environments and pasture types in Australia and overseas (Harper 1977; McIvor and Gardener 1994; Briske 1996; Batson 1999; Lodge 2001). The high number of annual grass and sedge seeds present in the soil seed bank suggests that any disturbance that creates bare ground, such as overgrazing, could result in a dramatic shift in botanical composition of the pasture. Hence, in this case, careful management of Bothriochloa within pastures would be important for maintaining composition.

Soil seed bank studies remain essential to complete our understanding of the whole regeneration pathway of species, from germination to adult reproduction, and for understanding and predicting community dynamics (Venn and Morgan 2010). Germination and recruitment events among perennial grass species may be episodic in nature (Briske 1996; King et al., 2006) only occurring when season conditions are ideal.

Acknowledgements

We thank the landholders on whose properties these experiments were conducted, Jim and Rosie Corrigan, David and Alison Hawthorn. This work was funded by Agriculture Victoria Research (and its predecessors) and the Dryland Salinity Collaborative Research Centre.

References


Simon, B.K. 1990. *A Key to Australian Grasses*. Queensland Department of Primary Industries, Brisbane.


Effects of *Parthenium hysterophorus* on grassland community in Nyando Sub-county, Kisumu County, Kenya

Mutua, B. M; Chiuri, W.
Department of Earth Sciences, Laikipia University, P.O. Box 1100-20300, Nyahururu, Kenya

**Key words**: invasive species; *Parthenium hysterophorus*; native grass species

**Abstract**

*Parthenium hysterophorus* is an invasive alien species native to South and Central America. The plant is ranked as one of the most dreaded weeds of the world. *Parthenium hysterophorus* affects grassland community through the release of allelochemicals that inhibit the germination and growth of grass species. However, little is known about its effects on native grassland community in Nyando sub-county of Kenya. Therefore, this study sought to investigate the effects of *P. hysterophorus* on grass species, livestock production and its control. A total of 121 farm household heads were interviewed using semi-structured interview schedules. Descriptive analysis and the T-test at 5% level of significance were used to analyse data. Sixty-three percent of respondents reported that *P. hysterophorus* replaced major native pasture species consequently reducing the quantity of milk yield per cow significantly by 3.81 litres. Majority households (98.3%) controlled *P. hysterophorus* by uprooting, slashing and hoeing while the remaining households used herbicides. The cost of controlling *P. hysterophorus* is expensive at about Kes. 6,253.33 per acre. *Parthenium hysterophorus* has the potential to negatively affect grasslands in Kenya with adverse impact on human livelihoods by reducing milk and beef production, lack of high quality nutrition food as well as the attainment of development targets such as those set in the Big Four Agenda, the Vision 2030 and the Sustainable Development Goals.

**Introduction**

Invasive Alien Species (IAS) are those organisms that are introduced into new regions where they get established and have adverse impacts on biodiversity, food security, health and economic development (Early *et al.*, 2016). IAS poses one of the greatest threats to biodiversity loss after climate change. Their distribution has been accelerated by the increase in world trade, transport, travel and tourism (Ziska and Dukes 2014). *Parthenium hysterophorus* is one of the most problematic IAS in Kenya. The weed is an annual herb native to South and Central America and now occurs as an alien invader in Africa, Asia and Australia (Bajwa *et al.*, 2016). In Kenya, the weed was first reported as a problematic weed in coffee plantations in the current Kiambu County in 1975 (Njoroge 1986). The weed has since been declared an obnoxious weed threatening biodiversity, agriculture and human health (Government of Kenya 2010). *Parthenium hysterophorus* is a very aggressive invader that replaces native plant species due to its high invasion rate coupled with allelopathic properties. The weed releases allelochemicals which inhibit the germination and growth of other plant species (Adkins *et al.*, 2018). Through the release of allelochemicals, *P. hysterophorus* directly competes with pasture species by reducing their vigour and seed set, leading to habitat and ecosystem change (Evans 1997). For instance, a study carried out in Queensland reported that *P. hysterophorus* significantly reduced pasture community diversity even when with relatively low densities (Nguyen *et al.*, 2017). Equally, the weed is reported to be responsible for pasture scarcity, bitter and non-palatable meat and milk, loss of weight and diarrhoea in livestock (Niguse and Kifle 2016). *Parthenium hysterophorus* has the potential of suppressing the immune system of livestock as demonstrated using the Wistar albino rat (Yadav *et al.*, 2010). Despite these adverse effects on livestock production, the control of *P. hysterophorus* is difficult. This is because *P. hysterophorus* produces a high number of seeds which have a prolonged seed viability of up to four to five year (Bajwa *et al.*, 2016). The weed has a rapid growth rate besides preference to wide range of ecological conditions for its establishment (Adkins *et al.*, 2018; Kaur *et al.*, 2014). Therefore, because of these reasons this study investigated
the effects of *P. hysterophorus* on grazing land, livestock production, farm labour requirement to control in Nyando sub-county, Kisumu County, Kenya. The information generated from this study can be used to enhance food security and in the attainment of development targets such as those set in the Big Four Agenda, the Vision 2030 and the Sustainable Development Goals.

**Materials and Methods**

This study was carried out in Nyando Sub-county, Kisumu County, Kenya. Out of 657 farm households whose farmlands had been invaded by *P. hysterophorus* and practised livestock keeping, a sample size of 121 households was determined using the Sample Size Calculator at 95% confidence level and 8.05% confidence interval (Creative Research Systems 2013). Simple random sampling was employed to select farm households to be interviewed by assigning each household a random number then picking 121 random numbers. Semi structured interview schedules (Mugenda and Mugenda 1999) were used to collected data on the effect of *P. hysterophorus* on livestock production, pasture availability and cost of controlling the weed. Data was analysed using the T-test with the aid of SPSS version 11.5 statistical computer software at 5% level of significance. The main economic activities in Nyando sub-county are subsistence farming, livestock keeping, rice and sugarcane farming, and small scale trading and therefore there was need to investigate the effects *P. hysterophorus* on human livelihoods (Government of Kenya 2013).

**Results**

Farm household interviews revealed that *P. hysterophorus* decreased the abundance of grass species. Majority of the respondents (63.3%) reported that *P. hysterophorus* formed dense colonies which replaced native pasture species. This decline was confirmed by field observations as *P. hysterophorus* was seen to dominate much of the grazing land as shown in photograph 1 below. Photograph 1: A section of grazing field in Nyando Sub-county highly invaded by *P. hysterophorus* (Source: Mutua, B. M. September 2018)

Our results also revealed that *P. hysterophorus* significantly contributed to an increase in livestock health complications. The average number of livestock health complications increased from 2.53 to 8.13 coughs, 2.17 to 8.10 diarrhoeas, 1.20 to 5.43 mouth ulcers, 1.33 to 4.23 deaths and, 1.07 to 4.87 emaciations cases per year. This increase in livestock disease incidents was significant at 5% level of significance. Milk production per cow was also reported to drop from 7.20 litres to 3.81 litres after the invasion of *P. hysterophorus* in the region. Paired samples T-test results confirmed that this decline in milk production per cow (mean of 3.392 litres) as a result of *P. hysterophorus* invasion was significant at 5% level of significance.

On weed control methods, majority (98.3% of the respondents) used physical methods (uprooting, slashing and hoeing) to control *P. hysterophorus* while only 1.7% respondents used herbicides to control. Control of *P. hysterophorus* was reported to significantly increase farm labour requirements with an average of Ksh. 10,111.67 on labour per acre per year prior to *P. hysterophorus* invasion compared to Ksh. 16,365 after the invasion of *P. hysterophorus* over the same time period. This significantly increased by 61.8% (Kes. 6,253.33 per acre) (p=0.000).

**Discussion [Conclusions/Implications]**

This study revealed that *P. hysterophorus* significantly decreased pasture species availability. These findings are consistent with those in Ethiopia which reported that *P. hysterophorus* critically endangers the biodiversity of grazing lands, particularly for the different native grass and forb species (Nigatu et al., 2017). Similar findings were also reported in a Queensland’s study, which revealed that *P. hysterophorus* significantly reduced pasture community diversity (Nguyen et al., 2017). The study also revealed that *P. hysterophorus* adversely affected livestock health. These findings were in agreement with the results of other studies. For instance, Niguse and Kifle (2016) reported that *P. hysterophorus* was responsible for the loss of weight and diarrhoea in livestock. Another related study reported that *P. hysterophorus* extracts reduced the number of white blood cells in Wistar albino rats an indicator of weakened immune systems (Yadav et al., 2010). Lastly, this study revealed that *P. hysterophorus* was mainly controlled through physical methods...
by uprooting, slashing or hoeing. These methods were reported to offer only a temporary solution and exposed farmworkers to the associated health risks (Kaur et al., 2014). Furthermore, farmers reported that *P. hysterophorus* control increased farm labour requirements. These findings were consistent with the findings of a study carried out in Tanzania which revealed that the labour for weed management was scarce and expensive (Wambura 2018). From the findings of this study, it was evident that *P. hysterophorus* invasion negatively affected pasture forage quantity and quality which consequently affected livestock carrying capacity hence compromised human livelihoods in Kenya leading to poverty and poor health.

**Acknowledgements**

The authors are grateful to the National Research Fund (NRF) for funding this research work and the coordinator Invasive Species – CABI Africa, Dr Arne Witt for the invaluable input to this research.

---

**References**


THEME 2. FORAGE PRODUCTION AND UTILIZATION

Topic: Tropical Forage Genetic Resources
Forage Genetic Resources in Brazil

Jank, L.; Santos, M.F.; Valle, C.B. do; Barrios, S.C.; Simeão, R.M.
Embrapa Beef Cattle, Rua Rádio Maia, 830, 79106-550, Campo Grande, MS, Brazil

Key words: accessions; germplasm; grasses, legumes; seed conservation

Abstract
To maintain the largest herd in the world, 214 million heads of beef cattle grazing exclusively on pastures (only 14% finished in feed-lots), Embrapa (Brazilian Agricultural Research Corporation) in Brazil, has intensely invested on forage breeding programs since the 1980s. Nowadays, there are circa thirteen forage grass and legume species being bred at different Embrapa Units around the country and other six Units focusing on collection and research of regional native forages. Breeding depends on good germplasm sources. Therefore, breeding activities in Brazil will remain highly dependent on exotic and native genetic basis maintained in the Germplam Banks. Despite the importance of forages to the country, genetic resources have still not received the attention they deserve. Most of the forage germplasm banks at Embrapa are maintained by breeders, who are also responsible for cultivar development activities, from germplasm evaluation and breeding to cultivar release to the market and thereafter. Thus, breeders lack the time to manage the banks adequately. Conservation is a challenge, since forage grass seeds usually lose viability quickly even under good conservation conditions and some accessions produce very low seed thus are being maintained vegetatively. Accessions maintained in the field impose problems of accession identity and varietal purity, and loss of plots due to invasive weeds or harsh climatic conditions. Although resources have been continuously available for maintenance, investments for evaluating and using are scarce. In general, accessions need to be better characterized, conserved and exchanged among researchers and institutions. Collection expeditions, mainly in Africa, are still imperative, since many genera, as Melinis and Hyparrhenia have not been collected and sexual forms in several apomictic species are not available or the sexual pools need broadening. Some important regions in Africa have not been assessed, as well as marginal areas to find sources of resistance to abiotic stresses.

Introduction
The area of pastures in Brazil totals 162.5 million hectares (Abiec 2020) including cultivated and native pastures. The continental dimensions of Brazil, with a favourable climate for the growth of forage plants and livestock, allowed Brazil to achieve a prominent position in the world scenario in recent years. Currently, Brazil has the largest commercial beef cattle herd in the planet, which corresponds to 14.7% of the world total, and is the second largest producer of beef and largest beef exporter.

Of this area, around 60 to 70% are occupied by cultivated pasture grasses of exotic species, introduced from the African continent, which, due to their apomictic reproduction, are of limited genetic variability and offer the danger to be decimated by disease outbreaks or pest attacks, demonstrating the vulnerability of our livestock system under grazing. The rest of the areas are occupied with a few grasses and legumes introduced from Africa or from the Mediterranean, or from native Brazilian species. In addition to animal nutrition, forage plants have great importance in maintaining productivity in crop rotation schemes, in fallow areas and in protecting the soil of sloping areas, which do not allow for sustainable use with agricultural crops.

Tropical forages are still little explored when compared to other crops, and account for practically all animal production (meat and milk) in Brazil, with only a few cultivars, specifically Panicum and Brachiaria, covering over 60 million hectares of pasture and accounting for more than 70% of the marketed seeds. The search for new cultivars is essential for the sustainability of the production and agribusiness processing of meat and milk in the country, either by new introductions or collections, or by the development of new cultivars in genetic improvement programs. For this reason,
Embrapa maintains forage germplasm banks spread throughout the country and coordinated by Embrapa Genetic Resources and Biotechnology in Brasilia, DF.

The germplasm banks are organized in four-year renewable projects pertaining to a macroprogram which includes all the plant, animal and microorganism germplasm banks of Embrapa. The objective of the project is to maintain, in an organized manner, Embrapa’s Forage Germplasm Banks through correct identification of accessions, maintenance of viability, genetic integrity, quality and availability of passport data, management and characterization through the Alelo System for access to basic information by the general public and users of germplasm banks.

Materials and Methods
The Project of Forage Active Germplasm Banks is coordinated by Embrapa Beef Cattle, and involves 12 germplasm banks, of which, eight of specific forages, and four regional banks. The specific forages active banks and collection contemplate 10 genera and are: Azevem (Lolium multiflorum) germplasm bank of Embrapa Temperate Agriculture in Pelotas, RS; Brachiaria, Panicum maximum and Stylosanthes at Embrapa Beef Cattle in Campo Grande, MS; elephant grass (Pennisetum purpureum) and collections of Cynodon and Setaria at Embrapa Dairy Cattle in Coronel Pacheco, MG; buffel grass (Cenchrus ciliaris) at Embrapa Semi-Arid in Petrolina, PE; Desmanthus at Embrapa Coastal Tablelands in Aracaju, SE; Paspalum at Embrapa Southeast Livestock in São Carlos, SP. The four regional banks are of importance to the regions: Mid-North Region at Embrapa Mid-North, in Teresina, PI; South Region at Embrapa South Livestock in Bage, RS; Cerrados Region at Embrapa Cerrados, in Planaltina, DF and Pantanal at Embrapa Pantanal, in Corumbá, MS.

Four activities are developed in this project: collection and/or introduction, germplasm characterization, germplasm conservation and documentation. The genebanks that may have collection activities because they are native forages are Paspalum, Mid-North Region, South Region, Cerrados Region and Pantanal Region. Characterization involves mainly morphological characterization of the accessions, but also cytogenetic and chemical, and agronomic performance, insect and disease tolerances etc. Conservation involves the regeneration of plants from seeds, maintenance of the accessions in the field, seed multiplication, conservation of the seeds in cold chambers at the Embrapa Units (temperature less than 10°C and humidity between 20 and 30%) and conservation of the seeds in long-term chambers at Embrapa Genetic Resources (humidity between 3 and 7% and -20°C temperature) in Brasilia, DF. Documentation consists of placement of passport as well as other data, such as morphological, agronomic, seed quantity and availability for exchange into Embrapa’s Alelo System (http://alelobag.cenargen.embrapa.br/AleloConsultas/Home/index.do).

Results
Until 2020, the germplasm banks were required to turn public the passport data of their banks in the Embrapa Alelo system. Thus, the number of official accessions in these banks are: Azevem – 240 accessions; Brachiaria – 213 accessions and Urochloa collection - 17 accessions; Panicum maximum – 429 accessions; Stylosanthes – 201 accessions; elephant grass – 145 accessions; collections of Cynodon and Setaria – 21 and 83 accessions, respectively; buffel grass – 116 accessions; Desmanthus – 445 accessions; Paspalum – 488 accessions; Mid-North Regional Bank – 72 accessions; South Region – 388 accessions and exotic legumes – 206 accessions; Cerrados Region – 2085 accessions and Pantanal Region – 94 accessions.

Specific characterization and conservation results are not the purpose of this paper, thus are not here presented.

Discussion | Conclusions/Implications
Embrapa has been investing in increasing germplasm since it was founded in the 1970s (Nass et al., 2012). Genetic resources have always been an important issue in Brazil, because it is the foundation of any breeding program. Brazil is essentially an agricultural country, and the genetic improvement of crops is fundamental to meet the productivity, quality and adaptation to the country’s conditions. Embrapa has 47 research centres, and one of them next to the main headquarters in Brasilia, DF, was constructed to enable research, development and innovation solutions in genetic resources for the sustainability of Brazilian agriculture and has acted strongly in the exchange and quarantine of plant germplasm, ensuring the continuity of Embrapa’s genetic improvement programs (Nass et al., 2012).

Most of the forage germplasm banks at Embrapa are maintained by breeders, who are also responsible for cultivar development, from germplasm evaluation and breeding to cultivar release in the market and thereafter. Embrapa maintains eight important different genera of forage grasses in their banks with over 1600
accessions and these are all managed by breeders. If on the one hand this is excellent because the breeder will ensure the use of the accessions in their breeding programs, on the other hand, the banks cannot be as well managed and conserved since the breeders cannot fully dedicate themselves to manage the banks adequately. To define, systematize and integrate all activities essential to the management, conservation and use of germplasm, through a coordinated management of the germplasm banks, the Embrapa Germplasm Curator System was created (Burle 2019), and the curators are the breeders.

Legumes are also represented in the banks of Stylosanthes and Desmanthus, forage Arachis (not included in this project) and exotic legumes in the South Bank, totalling over 800 accessions. However, there are many native legumes included in the Cerrados Bank which are not part of any breeding initiative. A few years ago, there were breeding programs of Cratylia and Leucaena, but these have been discontinued. Embrapa maintains in the long-term storage in Brasilia, 2537 accessions of 214 different species of legumes (Rocha 2014).

Forage grass seeds lose their viability very quickly, even under adequate storage conditions, so conservation is a challenge. To ensure viability, many banks maintain their accessions in the field, which imposes problems of accession identity and varietal purity, and loss of plots due to invasive weeds or harsh climatic conditions. Another particularly important issue is the lack of government investment in personnel to maintain the plots in good shape in the field.

Although resources have been continuously available for maintenance, investments for evaluating and using are scarce. In general, accessions need to be better characterized, conserved and exchanged among researchers and institutions. Once again, breeders do not always have the time to invest fully in germplasm bank activities.

From 1980 to around 2000, Embrapa invested much in germplasm collection in the country. However, new policies and cutback of resources have affected collection expeditions in general. Forage germplasm also depends on collection expeditions, mainly in Africa, since many genera, such as Melinis and Hyparrhenia have not been collected and sexual forms in several apomictic species are not available or the sexual pools need broadening. Some important regions in Africa have not been assessed, as well as marginal areas to find sources of resistance to abiotic stresses.

Thus, efforts are made to ensure the availability of forage genetic resources for the future of Brazil, but much still needs to be done and investments are necessary.

Acknowledgements
We acknowledge Embrapa for all the efforts in maintaining and increasing forage genetic resources for present and future generations.

References


Future generations – will any be lacking tropical forage genetic resources?

Maass, B.L.; Pengelly, B.C.

1University of Göttingen, Göttingen, Germany; 2Pengelly Consultancy Pty Ltd, Brisbane, Australia

Key words: conservation efficiency; global crop strategy; prioritization; research capability; tropical forage genetic resources

Abstract

It’s high time to stop talking about the (forage) plants and talk about the people. Three (Australia, India, USA) of the about a dozen curators of tropical and subtropical forage (TSTF) genetic resources collections involved in developing a Global Strategy on Conservation and Utilization of Tropical and Subtropical Forage Genetic Resources on behalf of the Global Crop Diversity Trust in 2015 have since retired. In all cases their replacements were not expert in this challenging commodity. Why? The commodity is highly diverse and requires understanding of a substantial body of knowledge generated over more than five decades. It requires a level of familiarity with two plant families, grasses and legumes, which comprise a plethora of genera and species. Some of these species, novel to agriculture, have been proven extremely useful for diverse livestock production systems, for environmental services and for people’s livelihoods. Others are rather ‘bycatch’ from early exploration and probably don’t deserve conservation at all, or at least at the highest genebank standards. Why were there no mentored scientists waiting to take up the vacant positions? There is today a worldwide shortage of applied plant research capability as “–omic sciences” or modelling seem more appealing to emerging scientists. Few budding agricultural scientists want to dedicate their career to a commodity, which mostly ranks low in recognition of its science merits and funding support. At the same time forage science and forages are coming under greater scrutiny because of environmental factors, especially in relation to the impacts livestock production is having on global warming. However, there are emerging scientists wanting to build a career in tropical forage science. Unfortunately, they are often disconnected from similar work around the world, and their own work is insufficiently recognized by aging, inward-looking institutions that still claim to lead global forage research and development despite the ever declining resources.

Background

“Apparently, the early phases of collecting and evaluation were much more valued than conserving and keeping the germplasm available for future generations”—twenty years ago, Maass and Pengelly (2001) recognized a drastic decline of interest in tropical and subtropical forage (TSTF) genetic resources after decades of pasture and forage research, particularly in Australia and tropical America. The lead TSTF research institutes of yesteryear have re-prioritized their research and development (R&D) programs with fewer and fewer requirements for TSTF germplasm from the collections in their genebanks.

This has occurred for several reasons. There is a view that the best-adapted species/genotypes for many of the tropical and subtropical production systems have been identified. Secondly, recent effort has been towards generating new diversity through grass breeding, particularly Brachiaria, in tropical America by the Centro Internacional de Agricultura Tropical (CIAT; now Alliance of Bioversity International and CIAT, ABIC) in Colombia and Embrapa, the national agricultural research organization in Brazil. Consequently, these institutions’ research teams have been drastically reduced in number as illustrated by Maass and Pengelly (2001, 2019). Furthermore, teaching of TSTF sciences at universities has been under threat everywhere (Maass and Pengelly 2001, 2019) and fewer young emerging forage scientists are being produced.

The question arises: who will be the future user generation for the very diverse conserved TSTF germplasm?
Declining Deployment for Decades

A germplasm-based strategy for new forage development used since the 1950s gave impressive productivity gains in large areas of tropical grasslands, particularly in Australia and tropical America. Since the 1990s, the R&D focus has shifted towards long neglected crop-livestock systems, including those of smallholders in developing countries. As the best-adapted species/genotypes for many of these systems have been identified, today there is very little focus on germplasm characterization or agronomic evaluation to identify novel species or accessions.

Several large and highly diverse TSTF germplasm collections arose from extensive exploration of potential species (Maass and Pengelly 2019; Schultze-Kraft et al., 2020). These are being conserved at major national and international institutions (Maass et al., 1997; Hanson and Maass 1999). A level of familiarity is required with two large and diverse plant families, grasses and legumes to manage this resource. It also requires familiarizing with a substantial body of comprehensive scientific and managerial knowledge that has been accumulated over more than five decades.

Twenty years ago, at the IGC in São Paulo/Brazil, Maass and Pengelly (2001) argued for more funding for TSTF germplasm and for better communication and networking among genebanks. They considered it crucial funding be improved before both germplasm and key knowledge was lost. Following that conference, a comprehensive database was established, which captured expertise from almost one hundred “experienced, often retired, forage specialists from across the globe”. That database and selection tool was launched as the “Tropical Forages Database” in 2005; it has since been updated and made useable on tablets and smart phones and re-launched in 2020 (Cook et al., 2020). Yet, even such an apparently well-used database has not created greater germplasm demand. Requests for germplasm remain low and, in the absence of evidence that the genetic resource base is playing a useful role, it will remain difficult to convince anyone to support conservation in perpetuity. Prolonged lack of use will ultimately result in the loss of the resource itself.

Discontinuation of Capability and Skills

Karaca and Ince (2019) claim that “researchers and staff involved in germplasm conservation … are expected to have knowledge and experiences in a variety of fields including biology, molecular biology, molecular genetics, plant systematics, population genetics, plant pathology, plant physiology, plant ecology, biochemistry, computer science, legal science, economics, and political science”; but that few institutes could provide such comprehensive professional training and mentoring for genebank teams. Those authors recognized that “many researchers and staff working in genebanks since the 1970s have retired or will retire soon” and that useful knowledge and experience in germplasm conservation will be lost. This scenario has played out with three experienced national TSTF genebank curators (Australia, India, USA) retiring in 2015. The two leaders of the international genebanks (CIAT and ILRI) retired at about the same time. The impacts of losing these leaders is significant, but even more so if they cannot be replaced by well-mentored scientists due to inadequate financial resources and/or because such comprehensively skilled researchers are rare.

Facilitating Greater Utilization and Rationalization

Future Forages Users

When beginning to implement the Global Strategy for the Conservation and Utilisation of Tropical and Sub-Tropical Forage Genetic Resources (Maass 2015), the authors only met a small number of active forage R&D teams (Table 1), especially those in Argentina and Brazil. Only some of these teams were really connected to a genebank by making use of TSTF germplasm. Several were much more engaged in laboratory-based “–omic sciences” or modelling, which seem more appealing to emerging scientists. Further, the teams were not connected with each other, a fact that underlines clear need for active networking. The Forages for the Future newsletter (Maass and Pengelly 2016-2019) connected diverse R&D groups by reporting on the latest TSTF efforts and their impacts. This certainly created more recognition for the work of several emerging scientists around the globe. Nevertheless, there are only few budding agricultural scientists wanting to dedicate their career to a commodity that mostly ranks low in recognition of its science merits and funding support.

Conservation for Future Generations

Williams (1983) considered the range of tropical legumes for their potential forage value and suggested that 228 legume genera and 3,902 legume species were potentially of merit. The international genebanks of CIAT and ILRI have assembled a large proportion of these: 188 genera and 1,268 species and a similar number of grass genera and species. Many of these are nothing more than ‘bycatch’ from early exploration and
probably do not deserve to be conserved for their forage potential. The *Tropical Forages Database* recognizes 172 entities (some of these are hybrids), but even that is probably massively optimistic. The reality is that ~30 TSTF species play a significant global role. This demonstrates that it is essential that genebanks with TSTF germplasm apply clear priorities to the species conserved and apply differential management based on those priorities. They need to focus their limited resources on what is important for future forage and environmental needs as current resource availability will not improve soon.

Future needs will be diverse but the following will be high amongst the many reasons why priority TSTF germplasm will play major roles:

- Impacts of emerging diseases or pests on used forages necessitating use of *ex situ* germplasm collection to select/breed for resistance;
- New plants required for farming systems that have to adapt to climate change impacts of temperature and water availability;
- New forage and pasture plants required for production systems that have to change because of their ecological footprint (non-climate change);
- Several priority species have little chance of recollection because widespread land use changes and habitat depletion have resulted in their near or total disappearance in environments of origin.

Table 1: Current situation of tropical and subtropical forage germplasm conservation, research, development and capability in selected countries/regions and future prospects

<table>
<thead>
<tr>
<th>Country/region</th>
<th>Status of TSTF germplasm</th>
<th>Situation of forage research and development and capability</th>
<th>Prospects for germplasm use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Very large collection; largely duplicated with CIAT and/or ILRI; recurrent funding issues.</td>
<td>A new TSTF expert in charge of germplasm. No forages/grassland R&amp;D program, institutionally part of ecosystem R&amp;D.</td>
<td>No ‘pipeline’ for novel spp. or new accessions from collection exists.</td>
</tr>
<tr>
<td>Argentina</td>
<td>No national, only state TSTF collections; no international distribution. Risk of germplasm loss.</td>
<td>Resource country for some grass and legume spp.; countrywide active in forage R&amp;D, focus on breeding, with several relative young people engaged.</td>
<td>Will continue to release TSTF cvs. adapted to some agro-ecologies; cv. use uncertain. Seemingly only small role for available germplasm.</td>
</tr>
<tr>
<td>Brazil</td>
<td>Large collection conserved centrally and in Active Germplasm Banks (‘BAG’ of Embrapa), partly with uncertain status; not available for distribution to other countries.</td>
<td>Very important as resource country for TSTF legumes; countrywide active in forage R&amp;D, focus on germplasm and breeding, with several relative young people engaged.</td>
<td>Will continue to release TSTF cvs. adapted to various agro-ecologies for important livestock production. May tap available germplasm directly and for breeding.</td>
</tr>
<tr>
<td>USA</td>
<td>Large national TSTF collection, partly with uncertain status; distribution to other countries. Seemingly little connection to active forage R&amp;D programs.</td>
<td>Lately more focus on native resources for diversifying grasslands and biodiversity maintenance. Some locally active teams (e.g. Texas, Florida).</td>
<td>Seemingly small role for available germplasm; no ‘pipeline’ seems to exist from germplasm collection to state programs.</td>
</tr>
</tbody>
</table>
Country/region | Status of TSTF germplasm | Situation of forage research and development and capability | Prospects for germplasm use
--- | --- | --- | ---
Eastern Africa (Kenya, Rwanda, Uganda, Tanzania, Ethiopia) | Some collections, with uncertain status; high risk of loss. Probably low availability for distribution. | Active forage teams, but aged, only partly younger researchers involved. Underfunded TSTF R&D when considering the need. | Largely dependent on germplasm from outside; germplasm collections largely disconnected from TSTF ‘real world’.

India | Two reasonable collections with uncertain status; distribution uncertain. | Large forage research team at IGFRI, relatively young, but high turnover of personnel, little long-term experience; active R&D programs. | Some use of available germplasm, but mainly breeding and –omics research. Germplasm collection seems disconnected from TSTF ‘real world’.

China | National collection with focus on native forage resources, conservation status unknown; availability for distribution uncertain. | Unknown. | Unknown.

CIAT (now, ABIC) | Very large collection, partly duplicated with ILRI and/or APG; in principle free distribution. | Important resource; TSTF curator in charge of germplasm; little connection to forage R&D program. | Currently, most TSTF research in grass breeding; no ‘pipeline’ from the germplasm collection exists for new uses.

ILRI | Large collection mostly duplicated with CIAT or APG; in principle free distribution, but little availability according to international standards. | Regionally important resource; needs application of priority and differential germplasm management. Relatively young team with focus on diversity research. | Forage R&D program focused on genetic improvement; germplasm collection disconnected from TSTF ‘real world’.

* ABIC, Alliance of Biodiversity International and Centro Internacional de Agricultura Tropical (CIAT); APG, Australian Pastures Genebank; BAG, Active Germplasm Bank of Embrapa, Brazil; IGFRI, Indian Grassland and Fodder Research Institute; ILRI, International Livestock Research Institute; R&D, research and development; TSTF, tropical and subtropical forages

**Conclusion and Outlook**
The authors have written many times of the parlous state of tropical and subtropical forage genetic resources. Not much has changed. This paper just repeats the arguments for the past 20 years.

Few budding agricultural scientists want to dedicate their career to a commodity that mostly ranks low in recognition of its science merits and funding support. At the same time, forage science and forages are coming under greater scrutiny because of environmental factors, especially in relation to the impacts livestock production is having on global warming. However, there are emerging scientists wanting to build a career in TSTF sciences. Unfortunately, they are often disconnected from similar work around the world, and their own work is insufficiently recognized by aging, inward-looking institutions that still claim to lead global forage research and development despite the ever declining financial resources.

If tropical and subtropical forage genetic resources are not worth keeping, then those global decision makers need to say so and, if they deem it necessary, decide what sort of effort should be made to keep the minimum. At the moment, the entire global TSTF genebank future seems to be destined to even more years of having limited resources and associated germplasm loss at scale. Those who have responsibilities need to recognize that, in the absence of decision making, future generations will not have access to even the
highest priority germplasm. Genebank managers need to realize that they have to focus on the most important. Policy makers, such as those who “manage” the Biodiversity Convention and its implications, need to recognize that, insisting that all germplasm is important and must be conserved using the best of best of practices is being decidedly unhelpful.

Without significant change, the future generations of scientists or other users that the world needs to conserve and underpin utilization of tropical and subtropical forage genetic resources will not be attracted to engage. Decisions must be taken rapidly; otherwise it soon be too late.

Acknowledgements
We wish to thank all those individuals and institutions that have enabled us to establish exciting and fulfilling professional careers by dealing for decades with tropical and subtropical forage genetic resources.

References


Rebuilding a tropical forages for the future network – a call for resuscitating enthusiasm for a commodity with great prospects and innovation potential

Pengelly, B.C.\textsuperscript{1}; Maass, B.L.\textsuperscript{2}

\textsuperscript{1} Pengelly Consultancy Pty Ltd, Brisbane, Australia; \textsuperscript{2} University of Göttingen, Göttingen, Germany

Key words: communication; forage genetic resources; networking; research focus; tropical forages;

Abstract

A series of Forages for the Future newsletters, outlining some of the latest tropical and subtropical forage (TSTF) research and development impacts and expertise, has been published since 2016. Amongst the research highlights were Brazilian scientists’ focus on grasses such as \textit{Urochloa}, \textit{Megathyrsus maximus}, \textit{Paspalum} and \textit{Cenchrus purpureus}, and on legumes, especially \textit{Arachis} and \textit{Stylosanthes}. Argentinian researchers are similarly targeting \textit{Acrorhiza macrum} and \textit{Setaria sphacelata}; while Indian and \textit{ILRI} (East Africa) researchers are using plant breeding to overcome disease constraints in Napier grass (\textit{Cenchrus purpureus} and associated hybrids). Also demonstrated were successfully using genetic resources of \textit{Desmanthus}, \textit{Leucaena leucocephala} and \textit{Macroptilium bracteatum} to improve Australian livestock production in varying farming systems on heavy-textured soils.

Amongst the most innovative forage-based development outcomes featured in the newsletters were the increasing role of \textit{Mucuna pruriens} in crop-livestock systems of semi-arid Zimbabwe, and the enabling role that forage grasses and legumes play in the \textit{icipe}-developed “push-pull”-system to control a range of pests in African maize farming-systems.

Some common threads stand out in these impact-delivering programs: longevity and ongoing institutional support, clear end-user focus, deep understanding of species adaptation and their phenotypic diversity and, how various species and ecotypes might be used.

These are just some of the successful research-for-development programs taking place across the tropics and subtropics; they provide an opportunity for strengthening TSTF research and development into the future. One missing ingredient is opportunity for teams from national, international centres and from the private sector to meet regularly to exchange results, ideas and challenges. International conferences and similar forums are expensive and too infrequent; but online options offer new communication approaches. The IGC in Nairobi is the perfect opportunity to discuss possible new collaboration forums and, if required, how they might operate to make for a better, well-informed and innovative international TSTF network.

Introduction

Research into tropical and subtropical forages species diversity, plant geography, adaptation, management and utilisation reached a peak between 1960 and 1990. Since then, there has been a steady decline in all disciplines associated with forages and pastures in the tropics and subtropics (Maass and Pengelly 2001, 2019; Pengelly and Maass 2019). Tropical forage research in the international institutes of the International Center for Tropical Agriculture (CIAT) and the International Livestock Research Institute (ILRI) is now a minor part of their portfolio. Similarly, national programs, which were at the forefront of tropical forage research such as those in Australia, Brazil, United States of America, India, Kenya, Zimbabwe, Argentina and Thailand, have all been significantly reduced.

In recognition of the need of a global approach for germplasm conservation, the Global Crop Diversity Trust commissioned development of global crop strategies for efficient and effective \textit{ex situ} conservation and utilization of crop diversity (Khoury \textit{et al.}, 2010). The “Global Strategy for
the Conservation and Utilisation of Tropical and Sub-Tropical Forage Genetic Resources” was developed in 2015 (Pengelly 2015) and subsequently implemented (Pengelly and Maass 2019). According to Pengelly and Maass (2019), “the strategy attempts to address the almost unanimous view from national and international genebanks that they were struggling to implement anything like best practice in genebank management, and that skills and resources had declined significantly”.

Towards a More Secure Genetic Resource Base

Improving Communication

The initial phase of implementation of the Global Strategy from 2016 to 2019 focused on better communication in the TSTF community and rationalization especially of the international genebanks (CIAT and ILRI). More than 600 recipients worldwide received a series of Forages for the Future newsletters with enthusiastic feedback. The newsletters connected diverse groups and outlined the latest TSTF research and development work and its impacts. However, with no means of continued funding the newsletter, after 3 years, is no longer being produced.

These Forages for the Future newsletters, which were published through the Global Crop Diversity Trust between 2016 and 2019 (Maass and Pengelly 2016-2019) highlighted some of the latest tropical and subtropical forage (TSTF) research and development, the impacts that research is delivering, and the teams that are undertaking the research. The highlights included Brazilian scientists’ focus on the grass genera/species Urochloa, Megathyrsus maximus, Paspalum and Cenchrus, and on a small number of legume genera, especially Arachis and Stylosanthes. The newsletter reported Argentine work on Acroceras macrum, Setaria sphacelata and several other grasses and Indian and ILRI (East Africa) researchers using plant breeding to overcome disease constraints in Napier grass (Cenchrus purpureus and associated hybrids). Also reported were the success from using selections from genetic resources of Desmanthus and Macroptilium bracteatum to improve Australian livestock production in varying farming systems on heavy-textured soils.

Amongst the most innovative forage-based development outcomes featured in the newsletters were the increasing role of Mucuna pruriens in crop-livestock systems of semi-arid Zimbabwe (Hommann-Kee Tui et al., 2015), and the enabling role that forage grasses and legumes play in the “push-pull”-system developed by icipe (International Centre of Insect Physiology and Ecology) to control a range of pests in African maize farming-systems (Kassie et al., 2018). In short, the contributions to the newsletters demonstrated that there are a whole range of benefits being delivered in farming systems around the tropics and subtropics from the development and better management of both grasses and legumes.

Conservation and Knowledge of Collections

During that same period (2016-2019) the authors travelled to research institutes in India, South America (Brazil and Argentina), Africa (Kenya and South Africa) and Australia, and to the relevant international institutes (CIAT and ILRI) to observe the status of the tropical and subtropical forage germplasm collections being held in those national and international genebanks. These visits followed on from a survey of national and international genebanks carried out by Pengelly (2015) and the Global Crop Diversity Trust in 2015 in which a large proportion of respondents reported that funding was decreasing and all reported difficulty in carrying out genebank operations (unpublished data).

The visits, survey and discussions with key TSTF researchers since all indicate that the collections being held are, at best, in moderate condition such as having large numbers of accessions with poor viability or having only limited viability data and a low proportion of accessions backed up in another genebank. In some national genebanks a large proportion of all the accessions being held are probably lost. In only a few cases could it be claimed that the collections were being conserved in anything approaching best practice.

Often, the moderate status of the collection’s conservation was accompanied by limited knowledge of diversity and potential value of species and accession being held. This is a consequence of both the size and diversity of the collections in both grass and legume families, and the rarity with which genebank managers can have an extended career in relevant tropical forage disciplines. This is not a criticism of those working in genebanks. Rather it is a comment on what happens when scientists are not able to have continued careers in genebanks, which enable them to gain a depth of knowledge across the range of relevant disciplines ranging from taxonomy, diversity, geography and plant adaptation to breeding systems and utilisation.

Building a comprehensive understanding of the collections is made even more challenging because of their size. Often the number of accessions is bloated due to over-enthusiastic,
poorly targeted collection (Maass and Pengelly 2019). The result is an overwhelming task of conserving large numbers of accessions of low-priority taxa, often with diminishing resources. This challenge can be overcome to some extent by prioritising the taxa being held in these collections (Cook and Schultze Kraft 2016), the development of the Tropical Forages Database (Cook et al., 2020) which summarises current knowledge about priority species, and greater collaboration between genebanks so that the challenges can be shared (Pengelly and Maass 2019). However, collaboration to enable more efficient conservation and to bring about better utilisation of priority taxa cannot just happen, especially in an environment of fewer resources. It has to be worked on.

**Networking**

An observation from interactions with TSTF genebanks is that both national and international genebanks are, to a large extent, working in isolation, with genebank managers and researchers having little or no communication with any other centres. In most cases, they have never met other TSTF genebank managers or researchers. This is in stark contrast to the “golden years” of the 1960-1990 period, when collaboration between centres was the norm and yielded so much. That collaboration led to not only exchange of germplasm but also exchange of ideas in the areas of taxonomy, geography, adaptation and utilisation. The collaboration, e.g. by joint research, long-term visits, joint collecting missions, free exchange of germplasm (Schultze-Kraft and Giacometti, 1979), was especially strong between genebanks in Brazil, the USA and Australia and the international institutes (CIAT and ILRI), but it was not limited to just these larger genebanks.

**How is Collaboration Rebuilt?**

Newsletters are fine to a degree, but they are not a substitute for personal interactions between researchers with common interests and goals. However, the higher profile of tropical and subtropical forage research of the golden years and the associated more generous research budgets that enabled international travel and extended visits of researchers to other institutes around the world is past. International conferences such as the International Grassland Congress (IGC) are expensive to attend and are too infrequent to alone be the avenue for ongoing collaboration and exchange of ideas. The difficulties in achieving collaboration before 2020 have been made more difficult by the COVID-19 pandemic and doubts about if and when low-cost international travel for research collaboration and conference attendance might resume. However, the benefits from collaboration are many and each aspect of collaboration has the potential to make genebanks more efficient and effective (Figure 1).

**Figure 1:** Some of the benefits that could be expected from greater collaboration among genebanks and tropical and subtropical forage researchers (modified from Pengelly and Maass 2019)
The COVID-19 pandemic has achieved a greater acceptance of the value and necessity of virtual meetings, of how they might be better conducted and chaired, and supported by a rapidly improving range of technologies. These changes perhaps offer a way forward for genebank staff to start to strengthen networks, sharpen the priority setting that almost all genebanks will be forced to undertake at some time, develop options to share the global conservation workload and, by working together, improve the understanding of what germplasm is being held for future generations.

Achieving a revitalised network of national and international tropical and subtropical forage genebanks will require leadership from one or national centres or from international agencies such as the Global Crop Diversity Trust (GCDT). Perhaps this is a task for a reformed Consortium of International Agricultural Research Centres (CGIAR). This will not be an easy task. It will require commitment over a long period by all, but especially by the international institutes, recognition of the challenges of different time zones, languages and the status, resources and roles of the various genebanks and careful thought to make engagement interesting and readily beneficial to participating genebanks. It has to avoid being a talkfest and an unwanted obligation.

Conclusion

It is proposed that tropical and subtropical forage genebanks must take drastic action to survive. Thirty years of decline in TSTF tropical forage research commitment by a range of agencies has resulted in genebanks being mostly in survival mode. Doing nothing will almost undoubtedly lead to further decline. The genebank managers who have taken on responsibility to conserve germplasm in perpetuity need to develop a better argument for sustained funding. That argument will need to be built around being more effective (providing the new germplasm for forage and environmental utilisation) and being more efficient. Efficiencies are achievable through active and engaged collaboration and a functional network of genebanks working on priorities.

Perhaps COVID-19 has provided a timely opportunity to have tropical and subtropical forages available in another 30 years from now. Livestock production for meat, milk, skins, fibre and draught will continue and those animals will require feed and sustainable feed production systems. Without a way forward to maintain genebanks and at least the priority germplasm as we know it today means that feed options will be lost forever to future generations.

References


Linking demand with supply for tropical forage genetic resources to reach impact at scale

Peters, M1; Burkart, S1; Ohmstedt, U1; Castiblanco, C1; Stern, E2; Nicolayevsky, A2; Enciso, K1; Diaz, M1; Mwendia, S1; Douxchamps, S1; Notenbaert1; Lukuyu, B3; Fuglie, K4

1Alliance of Bioversity International and CIAT; 2Grupo Papalotla; 3International Livestock Research Institute; 4USDA

Key words: tropical forages; adoption; scaling; seed supply systems

Abstract
Over the last decades a wealth of information on tropical forage genetic resources has been collated and is accessible to users ranging from farmers, development practitioners and researchers to decision makers and academia, e.g. through online tools such as Tropical Forages: An interactive selection tool (www.tropicalforages.info). However, while genetic diversity is being conserved by international gene banks, adoption of improved tropical forages is still far from reaching its full potential. Major bottlenecks in our view include lack of awareness of available forage genetic resources, confirmation of adaptation in a wide range of bio-physical, socio-economic, political and cultural contexts and functionality of financing, extension and seed supply systems. This paper discusses the potential for adoption of tropical forages in the context of new opportunities by market driven innovation, and presents early successes using as examples improved Urochloa spp., Megathyrsus maximus and other grass and legume germplasm, while describing possible pathways to go to scale with small and medium size livestock producers. We use examples of approaches from the tropical Americas, tropical Africa and tropical Asia, including partnerships with the private sector in diverse market environments (e.g. Africa and Latin America) and network approaches (Asia).

Introduction

Background. A key trend is the fast-growing demand for animal-source food in consumer baskets in the developing world as incomes rise. This is set to continue in coming decades, and will be pervasive across all livestock commodities and all developing countries (CGIAR Research Program on Livestock 2016). Feed is a key limiting factor and often the most expensive input in livestock production, accounting for about 50 to 60% of total production costs in ruminant-feeding systems (Swanepoel et al., 2010).

While there has been considerable development impact from planted forage cultivars, notably for Urochloa spp. and Megathyrsus maximus in Latin America (e.g. Jank et al., 2014), the adoption in tropical Africa and Asia is still lacking behind despite a widespread limitation in feed quality and quantity. There exists a wide range of suitable forages (Cook et al., 2020) and great variety of germplasm is available in gene banks. However, the so far limited adoption at farm level is attributed to a lack of awareness of available forage genetic resources, confirmation of adaptation in a wide range of bio-physical, socio-economic, political and cultural contexts and functionality of financing, extension and seed supply systems, the latter critical to ensure availability, accessibility and affordability of planting material. This paper aims to address potential approaches to overcome such bottlenecks and describe some examples of success.

Results and Discussion

Access to information and lack of awareness. There is considerable information on diversity and utilization of tropical forages. Tropical Forages, a tool for selecting forage species for local conditions, launched in 2005 (www.tropicalforages.info), is among the most widely used (~250-480k annual visits) and cited (450 citations) tropical forages databases, allowing selection of suitable forages according to specific agro-ecological conditions and then providing in-depth information. A new version of Tropical Forages was launched in 2020 with content updates and notable technical improvements, such as a revamped interface responsive to multiple...
devices, a mobile application and automatic translation, in particular the latter two aimed at enhancing reach at smallholder level. However, increasing the awareness of such tools and specific adaptation of information to local conditions are still needed to reach a much larger number of farmers. This would need to be supported by policy engagement reaching a wide range of stakeholders e.g. through roundtables and other multi-actor/innovation platforms.

Functional seed supply systems. A critical bottleneck to scaling forages are functional seed supply systems. Important criteria are a) availability, b) affordability and c) accessibility of seeds. To address a) and b), genetic characteristics, such as seed production potential, definition of suitable seed production environments and seed management production technology to maximize exploitation of the seed production potential, are required. For local seed production schemes, capacity building on seed production and business skills are essential. For long-term sustainability, this needs to go hand in hand with commercial viability, including market segmentation and providing cost-benefit calculations – both essential for an involvement of the private seed sector to reach impact at scale. For the latter, two main approaches are cost reductions (in particular for products without property rights) and developing differentiated products for targeted markets (protected for certain geographies or times). This is required to ensure return on investment and dedication, as can be seen with tropical grass is required to ensure return on investment and dedication, as can be seen with tropical grasses.

Examples of success in adoption of planted forages. A large part of forages adopted until recent are selections from wild relatives. In Latin America, a strong private sector in collaboration with the national research system has been instrumental to ensure adoption of planted forages. Exact data are scarce but Jank et al., (2014) estimate about 120 million ha planted with *Urochloa* (syn. *Brachiaria*) spp. and *Megathyrsus maximus* (syn. *Panicum maximum*), in Brazil alone. Planted forages are distributed through all of tropical America with large areas planted e.g. in Colombia, Argentina and Mexico.

For Asia, Stür et al., (2006, 2013) report more than 10,000 farmers adopting intensive grass production. The legume *Stylosanthes guianensis*, based on the accession CIAT 184, is reaching about 300,000 farmers as a cover crop and for leaf meal production in tropical China’s poultry and pig sectors (Guodao and Chakraborty 2005) and various *Stylosanthes* spp. are used by 250,000 farmers in India (Shelton et al., 2005). In Africa, the International Centre of Insect Physiology and Ecology (ICIPE) estimated the adoption of the push–pull system including forages by more than 30,000 farmers (Khan et al., 2011). Recent work coordinated by ILRI and CIAT in East Africa estimates scaling of *Brachiaria* germplasm selections (S. Ghimire, personal communication) and *P. purpureum* by up to 25,000 households in Eastern and Central Africa (Negawo et al., 2017; Staal et al., 2002).

More recently, there is an increased importance of bred forages supported by public-private partnerships as illustrated in the following example. In 2001, a *Urochloa decumbens* *brizantha* ’ *ruzienensis* cultivar coming out of CIAT’s breeding programme was released (Lynam and Byerlee 2017) as the first bred *Urochloa* cultivar to be documented. *Urochloa* hybrids have since then been commercialized through interaction with the private seed sector, namely the Papalotla Group (including Tropical Seeds) and Dow AgroSciences. Many adopters appear to be small- and medium-scale livestock producers (Papalotla, personal communication), although not equivalent to ‘smallholders’ as used in the African context. Recently, Papalotla registered advanced cultivars in Kenya and is commercializing through licensing agreements, aiming to expand in Eastern and Southern Africa. The original cultivar Mulato had limited commercial success due to low seed production and was replaced by Mulato 2 while higher seed production was included as an additional breeding objective. In subsequent years, a series of *Urochloa* hybrid cultivars were released, namely Cayman (tolerant to water logging), Cobra (more erect growth habit), Camello (better drought tolerance), Mestizo (synthetic mixture of 3 hybrids for better establishment and pasture utilization) by Papalotla and Converse by Dow Agrosciences. Additional cultivars and synthetic mixes with increased tolerance to drought and shade (e.g. for silvo-pastoral systems) are to be commercialized in the next 2–4 years (Papalotla, personal communication). The Alliance of Bioversity International and CIAT and
Papalotla are also advancing the development and commercialization of *Urochloa humidicola* and *Panicum maximum* breeding lines. The commercialized hybrids are planted on more than 1 million ha in more than 60 countries (see Table 1), the largest expansion so far in Latin America but expanding to other regions in particular in Eastern Africa.

Table 1: Area planted with *Urochloa* hybrids released under a PPP of the Alliance of Bioversity International and CIAT and Papalotla

<table>
<thead>
<tr>
<th>Region</th>
<th>Cultivated area in ha*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin America and Caribbean</td>
<td>970,692</td>
</tr>
<tr>
<td>Africa</td>
<td>5,147</td>
</tr>
<tr>
<td>Asia</td>
<td>9,572</td>
</tr>
<tr>
<td>Elsewhere</td>
<td>28,205</td>
</tr>
<tr>
<td>Total</td>
<td>1,013,615</td>
</tr>
</tbody>
</table>

*based on a seed rate of 7 kg/ha; vegetative propagation not accounted for

Estimates by Fuglie *et al.*, (2021, unpublished) indicate that across Latin America, Africa, and Asia (excluding China and southern cone countries of South America), it is likely that there are at least 158 million hectares under cultivated forage crops producing yield worth around $63 billion per year (at 2014-2016 prices). For Sub-Saharan Africa (excluding South Africa), this approximation suggests there may be 1.6 million hectares of cultivated forage crops currently grown in Sub-Saharan Africa. These estimates suggest that forage crops may be worth as much as $578 million per year in these countries. About 95 percent of this value is concentrated in East Africa, where about 60 percent of cow milk in Sub-Saharan Africa is produced (69 percent excluding South Africa) and where smallholder dairies in mixed crop-livestock systems predominate, mostly in Eastern African countries.

In another study, Born *et al.*, (2020, unpublished) highlight the potential of improved forages for replacing feed crops in the global tropics under future scenarios of aggravating climate change, increased population growth and demand for animal source foods.

In Asia, an attempt to link supply and demand was the creation of a research platform around forage legumes in 2018. Several research and governmental organizations from various countries committed to collaborate on research studies on the agronomic and environmental benefits of the integration of forage legumes into smallholder local production systems, as well as on a number of initiatives, including the establishment of a forage legumes rhizobia bank and the development of quality control guidelines to ensure high-quality inoculants. Information and germplasm exchange have been initiated in Vietnam, China, the Philippines, Cambodia, Indonesia and India, and testing of selected legume species have started in tree plantations.

Conclusions and outlook

We anticipate that over the next decades there is a continued and growing demand for animal-source food in consumer baskets in the developing world. One of the major costs of livestock production is feed production, while at the same time environmental concerns for livestock production are rising. Improved forages could be a pathway to sustainable intensification, addressing cost of production, productivity of increasingly constrained land resources, providing ecosystems services (e.g. greenhouse gas mitigation), and maintaining soil fertility. Adoption of forages however is still below its potential in particular in tropical Africa and Asia. In intensifying systems however, we observe an increasing demand for improved forages and various institutions are addressing the constraints to obtain accessible, affordable and available planting material. In various countries, in particular in Eastern Africa, we observe rapidly increasing adoption of improved forages and expect to see at least 100,000 forage adopters over the next 5 years (starting from 2019).

Acknowledgments

We acknowledge the support of multiple donors in advancing the work on tropical forages over the last decades.
References


THEME 3. LIVESTOCK PRODUCTION SYSTEMS

Topic: Small Ruminant Production Systems
Ewe daily-weight gain grazing *Leucaena leucocephala*-*Megathyrsus maximus* CV Mombasa silvopastoral system and tropical native unimproved range

Trejo-Arista, L. K.; Cortés-Díaz, E.; Martínez-Hernández, P. A.; Cadena-Meneses, J. A.

1Posgrado en Producción Animal, Universidad Autónoma Chapingo, Chapingo, México.

**Key words**: density, forage offered, weight gain.

**Abstract**

Silvopastoral systems are a viable option to increase livestock productivity. The silvopastoral arrangement of *Leucaena leucocephala* associated with *Megathyrsus maximus* CV Mombasa (LMS) is successfully cultivated in tropical environments. The objective of the study was to determine ewe daily-weight gain grazing LMS and a tropical unimproved native range. Two LMS were tested: high and low *leucaena* densities, 4700 and 2383 plants/ha, respectively. Grazing was rotational, lasted 150 d (rainy season) at equivalent stocking rate of 59 ewes/ha/150 d. Experimental design was a completely random design with three replications, the experimental unit was a 192 m² plot. Variables measured on plots were amount (dry matter basis), *in vitro* dry matter digestibility (IVDMD), and crude protein (CP) of forage on-offer, from mixed samples herbaceous and tree fodder. Weight and serum concentrations of Ca, P, K, Mg, Na, Zn, Cu, and Fe were measured in ewes, daily weight gain was calculated. On average forage on-offer and IVDMD concentration were 50 and 15% higher (p<0.05) in LMS than in native range, respectively, with no difference between LMS. CP concentration was 25% higher (p<0.05) in native range than both LMS, with no difference between them. LMS's showed no difference (p>0.05) between them on ewe daily weight gain, on average 59.2 g, and were higher than native range where ewes showed a mean daily weight loss of 14.8 g. Serum concentrations of the 8 minerals measured were similar (p>0.05) across all ewes regardless the treatments. It was concluded that the *Leucaena leucocephala*-*Megathyrsus maximus* CV Mombasa silvopastoral system is an option to improve livestock productivity compared with unimproved native range due to higher forage on-offer.

**Introduction**

Silvopastoral systems are sustainable livestock production alternatives as they improve both animal production indicators and environmental services (Gallego *et al.*, 2017). Sierra of Huautla is a protected reserve, in the state of Morelos, Mexico, and within its boundaries there are some communal tropical rangelands that support livestock grazing, from which small-holder farmers obtain some income. However, animal production indicators are low and some land and vegetation degradation have been associated to inadequate rangeland management and lack of rehabilitation protocols.

Silvopastoral systems adapted to the area could be an option to fight these two conditions: poor animal production and land and vegetation degradation (Murgueitio *et al.*, 2014). Alonso (2011) reported that silvopastoral systems with legume species improve soil fertility and cover, while Gaviria-Uribe *et al.*, (2015) added that planned silvopastoral systems that provide forage and browse increase total feed on-offer compared to single species pastures. The objective of the study was to compare the quantity and quality of forage and browse offered, as well as the changes in live weight in sheep at silvopastoral systems of *Leucaena leucocephala* associated with *Megathyrsus maximus* CV Mombasa and an unimproved native range.

**Materials and Methods**

The study was carried out in El Limón, Tepalcingo, Morelos, Mexico within the Huautla Sierra protected area, that has a semi-arid (up to 7-8 months of drought) tropical climate and vegetation of deciduous shrubs and low trees. Three treatments were evaluated: *Leucaena leucocephala*-*Megathyrsus maximus* CV Mombasa silvopastoral systems at two *L. leucocephala* densities, high (LMSH) and
low (LMSL) and a control treatment of native unimproved range (NUR). Experimental design was a completely randomized design with three treatments and three replications. The experimental unit was a 192 m² plot.

LMSH and LMSL were established and fenced at the start of the rainy season of the year before experimental grazing was carried out, NUR plots were fenced at this time as well. Leucaena plants were grown in nursery for two months prior to planting on the field. Planting of leucaena plants was done in rows 2 m apart, at 4700 and 2383 plants/ha for LMSH and LMSL, respectively, Mombasa grass was sown in rows within leucaena rows at 8 kg seed/ha. Experimental grazing lasted 150 d during the 2015 rainy season, just before grazing started tree/shrub count was done in the NUR plots, on average they showed 300 plants/ha. Grazing was rotational with 21-28 d of resting, the stocking rate was 59 ewes/ha.

Variables assessed were: on-offer (Haydock & Shaw, 1975) forage and browse on dry matter basis, in vitro dry matter digestibility (IVDMD; Barnes, 1969) and crude protein (CP; AOAC, 1984); and, ewe weight and serum Ca, P, K, Mg, Na, Zn, Cu, and Fe concentrations (Fick et al., 1979), daily weight gain was calculated, serum mineral concentrations were determined at the start and end of the experimental grazing. Statistical analysis was by analysis of variance using PROC GLM of SAS (SAS 9.4, 2014). If a main effect was significant (p≤0.05) least square mean multiple comparison was done using Tukey at α = 0.05.

Results

LMSH and LMSL had similar (p>0.05) yield of forage on-offer which was 2.2 times higher (p<0.05) than NUR, while in browse on-offer LMSH had the highest yield which was 2.2 and 22 times higher than LMSL and NUR, respectively; however, LMSH and LMSL provided similar (p>0.05) total feed on-offer during the rainy season (Table 1).

Table 1: Forage, browse and total feed on-offer (kg DM/ha) at three systems during the rainy season.

<table>
<thead>
<tr>
<th>Silvopastoral system</th>
<th>Forage</th>
<th>Browse</th>
<th>Total feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMSH*</td>
<td>8936±506.2ª</td>
<td>218±42.2ª</td>
<td>9154±534.4ª</td>
</tr>
<tr>
<td>LMSL</td>
<td>7841±737.4ª</td>
<td>98±24.8ª</td>
<td>7939±754.6ª</td>
</tr>
<tr>
<td>NUR</td>
<td>3712±108.8ª</td>
<td>10±4.5ª</td>
<td>3722±107.0ª</td>
</tr>
</tbody>
</table>

*LMSH, Leucaena leucocephala-Megathyrsus maximus at 4700 plants/ha; LMSL, Leucaena leucocephala-Megathyrsus maximus at 2383 plants/ha; NUR, native unimproved range at 300 trees/ha. Means within columns with one letter in common are not statistically different (Tukey, α=0.05).

Silvopastoral system influenced (p<0.05) IVDMD and CP of forage on-offer, with no effect (p>0.05) on browse on-offer quality measurements. LMSH showed the lowest forage IVDMD on-offer, while NUR had 1.5 times higher forage CP on-offer than the mean of the other two silvopastoral systems that had similar CP content in the forage on-offer. Ewes grazed on NUR lost (p<0.05) weight while ewes grazed on the two leucaena systems had similar weight gain (P > 0.05) (Table 2).

Table 2: In vitro dry matter digestibility (IVDMD), crude protein (CP) of forage and browse on-offer and ewe daily weight gain (DWG) at three systems.

<table>
<thead>
<tr>
<th>Silvopastoral system</th>
<th>Forage IVDMD(%)</th>
<th>Forage CP(%)</th>
<th>Browse IVDMD(%)</th>
<th>Browse CP(%)</th>
<th>DWG, g/ewe/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMSH*</td>
<td>46±3.5ª</td>
<td>67±1.5ª</td>
<td>7.8±1.1ª</td>
<td>22.7±1.8ª</td>
<td>53±9.4ª</td>
</tr>
<tr>
<td>LMSL</td>
<td>61±2.4ª</td>
<td>61±6.6ª</td>
<td>7.0±0.3ª</td>
<td>21.6±2.8ª</td>
<td>65±18.3ª</td>
</tr>
<tr>
<td>NUR</td>
<td>61±6.1ª</td>
<td>56±4.0ª</td>
<td>11.7±0.7ª</td>
<td>19.2±2.4ª</td>
<td>-15±5.23ª</td>
</tr>
</tbody>
</table>

*LMSH, Leucaena leucocephala-Megathyrsus maximus at 4700 plants/ha; LMSL, Leucaena leucocephala-Megathyrsus maximus at 2383 plants/ha; NUR, native unimproved range at 300 trees/ha. Means within columns with one letter in common are not statistically different (Tukey, α=0.05).
Mineral serum concentrations were similar (p>0.05) among ewes regardless the silvopastoral system assigned, with the exception of P content, where ewes grazed on NUR had 13% less P than ewes grazed on LMSH at the end of the experimental grazing period. At the end of the experimental period, ewes grazed on all three systems had lower concentrations of Mg, Na, and Zn than those reported by Puls (1988; Table 3).

**Table 3**: Mineral serum concentrations (mg/L) in ewes at the start and end of experimental grazing in three systems.

<table>
<thead>
<tr>
<th>Silvopastoral system</th>
<th>Mineral</th>
<th>Ca</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Na</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Start</td>
<td>LMSH</td>
<td>LMSL</td>
<td>NUR</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>72±0.8</td>
<td>74±3.5</td>
<td>80±4.3</td>
<td>85±6.6</td>
<td>90-130</td>
<td>107±2.6</td>
<td>170±32.5</td>
<td>167±36.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±0.8</td>
<td>±3.5</td>
<td>±4.3</td>
<td>±6.6</td>
<td>±10-130</td>
<td>±2.6</td>
<td>±32.5</td>
<td>±3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>106±2.5</td>
<td>121±4.4</td>
<td>109±3.7</td>
<td>107±2.6</td>
<td>40-80</td>
<td>40-80</td>
<td>170±32.5</td>
<td>137±31.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±2.5</td>
<td>±4.4</td>
<td>±3.7</td>
<td>±2.6</td>
<td>±20-80</td>
<td>±2.6</td>
<td>±32.5</td>
<td>±1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.7±1.8</td>
<td>6.0±1.4</td>
<td>7.7±0.5</td>
<td>8.0±0.5</td>
<td>156-214</td>
<td>20-35</td>
<td>1461±7.5</td>
<td>1471±52.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±1.8</td>
<td>±1.4</td>
<td>±0.5</td>
<td>±0.5</td>
<td>±20-80</td>
<td>±20-35</td>
<td>±0.043</td>
<td>±0.032</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7±0.7</td>
<td>0.5±0.7</td>
<td>0.5±0.5</td>
<td>0.5±0.5</td>
<td>156-214</td>
<td>20-35</td>
<td>1461±7.5</td>
<td>1471±52.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±0.7</td>
<td>±0.7</td>
<td>±0.5</td>
<td>±0.5</td>
<td>±20-80</td>
<td>±20-35</td>
<td>±0.043</td>
<td>±0.032</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.1±0.9</td>
<td>2.9±3.0</td>
<td>2.3±0.6</td>
<td>2.8±0.7</td>
<td>90-130</td>
<td>40-80</td>
<td>1461±7.5</td>
<td>1471±52.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±0.9</td>
<td>±3.0</td>
<td>±0.6</td>
<td>±0.7</td>
<td>±10-130</td>
<td>±2.6</td>
<td>±7.5</td>
<td>±0.7</td>
</tr>
</tbody>
</table>

*LMSH, *Leucaena leucocephala-Megathyrsus maximus* at 4700 plants/ha; LMSL, *Leucaena leucocephala-Megathyrsus maximus* at 2383 plants/ha; NUR, native unimproved range at 300 trees/ha; R, suggested concentration (Puls, 1988). Means within columns with one letter in common are not statistically different (Tukey, α=0.05).

**Discussion [Conclusions/Implications]**

Planned arrangement of fodder trees (leucaena) and introduction of an improved grass (cv Mombasa) caused a large increase in the supply of forage, browse and total feed in the silvopastoral system treatments compared to the native distribution area. In these systems 8 and 16 times more trees were used than those found in the native range. The above, added to the fodder vocation of leucaena, explain the greater amount of browse in silvopastoral systems. Echavarría *et al.*, (2007) agree on these both conditions to explain the higher feed available in planned silvopastoral systems compared with native ranges. Torres-Acosta *et al.*, (2008) reported that in planned silvopastoral systems fodder trees are kept at a similar canopy height, while in native range upper canopy could be variable in height and then in browse yield. Reid *et al.*, (2014) pointed out that in the evaluation of planned silvopastoral systems wildlife feeding and shelter should be determined in addition to animal production of livestock.

The better ewe performance measured by daily weight gain in both leucaena systems compared with the NUR, could be explained on basis of the higher amount of feed on-offer in those two leucaena systems, rather to differences in feed quality. The IVDMD and CP were similar for browse on-offer in all treatments, which shows that the nutritional value of the trees found in the native range is similar to that of leucaena. This highlights the fodder potential of these species and the need to include them in the design of silvopastoral arrangements to evaluate their performance. The IVDMD of forage on-offer was lower in the treatment with a higher density of leucaena. The CP of forage on-offer was higher in the native range. This shows that the herbaceous plants of the native range have a higher nutritional value than the grass cv Mombasa. The only mineral that presented variations during the experiment was phosphorus in the treatment with the highest amount of leucaena. It can be deduced that the duration of this work was not sufficient to observe an effect on the concentration of minerals in the blood serum of the animals that grazed in the treatments.

It was concluded that planned silvopastoral systems based on *Leucaena leucocephala* at high plant density along with an improved tropical grass are an option to improve animal performance compared with native tropical range. Environmental services of such planned silvopastoral systems are still to be elucidated.
Acknowledgements:
We thank the National Science and Technology Council, Universidad Autónoma Chapingo for financial support and El Limón people for their help and involvement in all the field work.

References
Impact of fescue toxicosis on fetal development and postnatal growth

Duckett, S. K.; Greene, M. A.; Britt, J. L.; Andrae, J. G.
Clemson University, Clemson, SC, USA 29634

Key words: tall fescue, ergovaline, fetal development, milk production, growth

Abstract
Tall fescue (Lolium arundinaceum [Schreb.]) is the most common cool-season perennial pasture grass in the United States. Most hectares are infected with an endophytic fungus, Epichloë coenophiala. Two experiments evaluated the impact of exposure of ewes to one of two fescue treatments: endophyte-infected [E+] tall fescue seed or endophyte-free [E-] tall fescue seed) fed during two stages of gestation, MID (d 35 to 85) or LATE (d 86 to 133 or parturition) in a 2 x 2 factorial. In experiment 1, ewes (n = 32) underwent terminal surgeries at d 133 of gestation to examine placental and fetal tissues. In experiment 2, ewes (n = 56) went to term and lamb growth was evaluated from birth to finish. Exposure to E+ fescue during LATE gestation reduced placental mass, and total fetal weight per ewe was lower by 15% for ewes fed E+ fescue seed. However, feeding E+ fescue seed during MID gestation did not alter total fetal weight per ewe. Fetuses from dams fed E+ fescue during LATE gestation had larger brain weight as a percent of body weight, which is indicative of intra-uterine growth restriction. At birth, lamb weights were reduced for ewes exposed to E+ fescue during LATE gestation. Furthermore, exposure to ergot alkaloids during MID and LATE gestation reduced ewe milk production. Ewe lambs from dams fed E+ fescue from d 35 to birth had reduced weaning weights but finished weights did not differ for wethers. Ewe lambs born to ewes fed E+ during LATE gestation were smaller and took longer to reach puberty. This work supports the hypothesis that exposure to ergot alkaloids during gestation alters fetal development, milk production and lamb growth.

Introduction
Tall fescue (Lolium arundinaceum [Schreb.]) is the predominant cool-season perennial pasture grass in the United States. Most hectares are infected with an endophytic fungus, Epichloë coenophiala. The endophyte is beneficial to the plant, aiding establishment, persistence, and drought tolerance (Stuedemann and Hoveland 1988). However, ingestion of the ergot alkaloids by grazing livestock results in fescue toxicosis which reduces animal growth and reproductive performance (Roberts and Andrae 2018). Ergot alkaloids are dopamine agonists and when consumed they depress serum prolactin and induce vasoconstriction. Ergovaline and ergovalinine are the main (84-97%) ergot alkaloids produced by endophyte-infected tall fescue (Strickland et al., 2011; Foote et al., 2012). Ergovaline has also been shown to be a potent vasoconstrictor in the bovine umbilical and uterine arteries (Dyer 1993), which can reduce blood flow to developing placental tissues and fetus.

Less is known about impact of fescue toxicosis on fetal programming and the subsequent growth of the offspring. Maternal consumption of ergot alkaloids via endophyte-infected tall fescue pasture or tall fescue seed results in reduced birthweights in calves (Watson et al., 2004) and lambs (Duckett et al., 2014). Greenwood et al., (2005) suggested that restrictions in maternal nutrition from 80 d of gestation to parturition limits subsequent postnatal growth of the offspring. Symonds et al., (2010) recorded that maternal nutrient restriction at specific stages of gestation can alter offspring long-term. Subsequent postnatal growth of offspring exposed to ergot alkaloids in utero has not been examined. Two experiments were conducted to: 1) determine how ergot alkaloid exposure during specific times of gestation alter fetal development, and 2) examine how ergot alkaloid exposure during mid- and/ or-late gestation alters subsequent post-weaning growth, puberty attainment, and carcass quality in lambs.
Materials and Methods

Experimental Design. All animal experimental procedures were reviewed and approved by the Clemson University Institutional Animal Care and Use Committee (AUP 2014-081). In both experiments, pregnant ewes were used in a 2 x 2 factorial arrangement with two fescue seed treatments (endophyte-infected, E+ vs. endophyte-free, E-) fed during two stages of gestation (MID, d35 to 85 and/or LATE, d 86 to 133), which created four possible treatments (E+/E-, E+/E+, E-/E- or E-/E+). Endophyte-infected (E+; ‘Black Magic’ turf-type tall fescue) seed was fed in this study to supply a daily dose level of 1.77 mg animal-1 d-1 of ergovaline and ergovalinine for E+). The same weight of endophyte-free (E-; ‘Bull’ turf-type tall fescue) tall fescue seed was fed to supply 0 mg animal-1 d-1 of ergovaline and ergovalinine. Tall fescue seed was mixed into a total ration each morning before feeding according to treatment. Ewes were individually fed their respective treatment diet daily. Diets were formulated to meet the requirements for pregnant ewes with twins during early and late gestation. Feed intake and body weight changes during the study were recorded. In experiment 1, ewes (n = 32) underwent terminal surgery on d 133 of gestation where fetuses were removed and euthanized. In experiment 2, ewes (n = 56) went to term and lambs were followed from birth to puberty (ewe lambs) or market weight (wethers) to assess impact of in utero exposure to ergot alkaloids on subsequent fetal growth. Additional information on experimental design and animal management are available in Britt et al., (2019, 2020) and Greene et al., (2019, 2020). After parturition, all ewes were fed the total mixed ration without any feed. Birth weights were collected on all lambs at birth. Ewes and their lambs were individually stalled in lambing jugs for 48 hours following parturition to facilitate bonding and estimate milk production. Ewes were placed on a two-day milk production test following parturition. At 0800, ewes were milked out by hand and a dividing panel was positioned within the lambing jug to allow nose-to-nose contact but prevent nursing. After three hours, dams were milked out by hand and the milk weighed. Lambs were bottle fed the collected milk and the dividing panel was removed. This procedure was also repeated at d 21 with dams and lambs separated in different pens for the three-hour duration. Male lambs were castrated (wethers) within 7 d of birth. Weaning of the lambs from the dams occurred at 75 ± 2 d of age.

Ewe lambs. At weaning, ewe lambs (n = 39) were maintained on non-fescue pasture and supplemented with High Energy Lamb Grower feed (Southern States, Richmond, VA) for a targeted weight gain of 114 g/d. Plasma samples were collected weekly to evaluate progesterone concentrations using a progesterone ELISA kit (Cayman Chemical, Ann Arbor, MI) to estimate puberty attainment. Plasma samples were purified using methylene chloride to minimize cross reactivity during progesterone analysis. The progesterone ELISA kit had an inter-assay and intra-assay variance of 3.66% and 7.90%, respectively. A threshold concentration of 1.0 ng/ml progesterone in plasma has been established as the level indicative of puberty attainment in ewe lambs.

Wether Lambs. At weaning, wethers (n = 43) were allocated to pens and individually fed a concentrate diet, ad libitum, twice daily and intake was recorded. Wethers were given a two-week period at the start of feeding where hay was provided to facilitate the transition to a concentrate diet. All wethers received High Energy Lamb Grower (Southern States) for the growing period (weaning – 40.82 kg) and High Energy Lamb Finisher during the finishing period (40.82 kg – 56.70 kg or d 185 post-weaning). At the end of the finishing period, wethers were fasted for 12 h prior to slaughter and live weight was obtained. Wethers were transported 15 km to the Clemson University Meat Laboratory for slaughter. The carcass was chilled at 4°C for 24 h and then chilled carcass weight obtained. Carcasses were ribbed at 12/13th rib and standard carcass measurements collected.

Statistical analyses. Data were analysed using a mixed model (SAS 9.4, SAS Inst. Inc., Cary NC) as a 2 x 2 factorial with in utero fescue seed treatment (E- or E+) stage of gestation (MID or LATE) and the interaction in the model. Lamb numbers born or raised per ewe was included as a covariate when significant (p < 0.05). Least square means were generated and tested using protected least significance difference test. Significance was determined at P < 0.05 with trends at P < 0.10.

Results

Feeding endophyte-infected (E+) tall fescue seed to ewes lowered serum prolactin and carotid luminal area indicating efficacy of treatment to induce fescue toxicosis and vasoconstriction. Feeding endophyte-infected (E+) tall fescue seed during late gestation reduced (p < 0.05) fetal weights by 15% and birth weight by 12% compared to ewes fed E- fescue seed during mid and late gestation (Fig. 1). Exposure to E+ fescue during mid gestation (E+/E-) did not alter (p > 0.05) fetal or birth weights compared to E-/E-.
Exposure to E+ fescue during LATE gestation reduced (p < 0.01) placental mass. Fetuses from dams fed E+ fescue during LATE gestation had larger (p = 0.019) brain weight as a percent of body weight, which is indicative of intrauterine growth restriction (IUGR).

**Figure 1**: Fetal weight on d 133 of gestation (experiment 1) and birth weight (experiment 2) from ewes fed endophyte-infected (E+) or endophyte-free (E-) tall fescue seed during mid (d 35 to 85) and/or late (d 86 to 133 or parturition) gestation.

Exposure to ergot alkaloids during MID and LATE gestation reduced (p < 0.05) ewe milk production on d 1, 2 and 21 of lactation. On d 1 and 2 of lactation, ewes that were fed E+ fescue seed at any stage of lactation had lower (p < 0.05) milk production than E-. On d 21 of lactation, ewes fed E+ fescue seed during MID gestation had lower (p < 0.05) milk production than ewes fed E- seed. Lambs from dams fed E+ fescue from d 35 to birth (E+/E+) had 15% lower (p = 0.0091) weaning weights. Ewe lambs born to ewes fed E+ during late gestation had slower (p < 0.05) gains post-weaning and took longer (p = 0.059) to reach puberty (11 d longer on average). Wether lambs born to ewes fed E+ seed during both MID and LATE gestation (E+/E+) had slower (p = 0.44) pre-weaning average daily gains but gains did not differ post-weaning. Carcass characteristics were not altered by in utero fescue exposure, but tenderness of leg muscles was reduced (p < 0.05) in the E+/E+ treatment.

**Discussion**

Over 80% of fetal growth occurs during last trimester of gestation (Rattray et al., 1974) and exposure to E+ fescue seed during this time reduced fetal and birth weight of lambs. These results demonstrate that E+ tall fescue seed fed during late gestation reduces fetal weight and causes asymmetrical growth, which is indicative of intrauterine growth restriction (IUGR). Exposure to E+ fescue, regardless of stage of gestation, also reduced milk production in ewes and lowered average daily gains in pre-weaning period. After weaning, ewe lambs born to ewe fed E+ during late gestation had slower growth rates and delayed puberty compared to those born to E- ewes. Wether lambs were able to compensate for delayed growth during the finishing phase when fed high concentrate diet and carcass traits were not impacted. Overall, ergot alkaloid exposure during gestation alters fetal development, milk production and pre-weaning growth rate of offspring. Offspring born to dams exposed to ergot alkaloids during gestation had delayed puberty and reductions in product quality.

**Acknowledgements**

This research was supported by USDA Agriculture and Food Research Initiative Competitive Grant no. 2015-67015-23218.

**References**


Simulation of alternative plans for community based goat breeding program in arid, semi-arid and mixed production systems in Ethiopia

Jembere, T1; Rischkowsky, B2; Dessie, T3; Kebede, K4; Okeyo Mwai, A5; Mirkena, T6; Haile, A2

1Bako Agricultural Research Center, P O Box 03, West Shoa, Ethiopia; 2International Centre for Agricultural Research in the Dry Areas, Addis Ababa, Ethiopia; 3International Livestock Research Institute, Animal Science for Sustainable Productivity Program, Addis Ababa Ethiopia; 4Schools of Animal and Range Sciences, Haramaya University, Haramaya, Ethiopia; 5International Livestock Research Institute, Animal Science for Sustainable Productivity Program, Nairobi, Kenya; 6School of Animal and Range Sciences, College of Agriculture, Hawassa University, Ethiopia

*Corresponding author: tjbakara@yahoo.co.uk

Key words: breeding scenario; genetic gain; genomic selection; selection group; simulation

Abstract
On station small ruminant researches in Ethiopia were ineffective due to various factors. As alternative, community based breeding program (CBBP) has emerged. In the current CBBPs, sire side selection only (SN1) is practiced. The objective of the present work was to compare SN1 by simulating alternative breeding scenarios for Abergelle (AB), Central Highland (CH) and Woyto-Guji (WG) goat breeds in Ethiopia. Three scenarios including selection on dam side (SN2) in addition to SN1, application of genomic selection (SN3) onto SN1 and use of sires from SN1 for mating in additional flocks (SN4) were simulated and compared with SN1 based on the predicted annual genetic gain (PAGG) and discounted profits. The breeding objective traits or selection criteria were six month weight (6mw, kg) for all breeds, average daily milk yield (ADM, kg) and survival to six month of age (SURV) for AB, litter size at birth (LSB) for CH and WG, litter size at weaning (LSW) for CH and kidding interval (KI, days) for WG. ZPLAN+ software was used for the simulation. The PAGG for 6mw (kg) ranged from 0.087 (SN4) to 0.25 (SN3) for AB where it ranged from 0.47 (SN4) to 0.97 (SN3) for ADM (kg) for same breed. PAGG in 6mw (kg) ranging from 0.13 (SN4) to 0.47 (SN3) and from 0.20 (SN4) to 0.31 (SN3) for CH Gonder and Ambo sites, respectively were simulated whereas this parameter ranged from 0.10 (SN4) to 0.27 (SN3) for WG. The alternative breeding scenarios to SN1 resulted in better PAGGs, especially for 6mw in three of the goat breeds and for ADM in AB. Based on the PAGGs and profitability, we recommend SN2 over SN1. However, SN4 could also be applied, compared to SN1, in view of suitability of addressing emerging demands.

Introduction
On station small ruminant researches in Ethiopia were ineffective due to various factors. Community based breeding program (CBBP), thought to be an alternative to the on station research, is design of breeding scheme that is deemed suitable for smallholder farming system (Gizaw et al., 2014). The CBBPs for small ruminants have been established in different parts of the world; for sheep and goats in Ethiopia (Duguma et al., 2011), for goats in Mexico (Wurzinger et al., 2013) and in Iran (Mueller et al., 2015).

In Ethiopia, indigenous goats make valuable contributions, especially to the poor in the rural areas. Ethiopia owns about 12 indigenous goat breeds where eight of them are reared for their milk production in addition to meat, manure and skin products (ESGPIP 2008). Where the recent goat population of Ethiopia was reported to be 30.20 million (CSA 2017), it was considerably smaller than the sheep population of the country. However, since very recently, the ratio of goat to sheep showed an increasing trend; 0.93 (CSA 2012), 0.99 (CSA 2015) and 0.98 (CSA 2017) which might be an indication that goats are becoming equally important as sheep in Ethiopia.

Implementation of CBBP of three indigenous goats in Ethiopia was executed by the leading role
of Bioscience for eastern and central Africa and International livestock research Institute (BecA-ILRI) in six villages (CBBP sites). The breeds included Abergelle kept in arid pastoral, Central Highland inhabiting crop-livestock production system and Woyto-Guji within semi-arid agropastoral production systems (Tatek et al., 2016). In the current CBBPs, sire side selection only (SN1) was practiced. The objective of the present work was to compare SN1 by simulating alternative breeding scenarios for Abergelle (AB), Central Highland (CH) and Woyto-Guji (WG) goat breeds in Ethiopia.

Materials and Methods

Description of the study sites
Optimization scenarios were based on the data collected from CBBP sites established in two villages per breed. From each of the two sites for Abergelle (AB) and Woyto-Guji (WG), averages number of breeding females were considered (the two villages per AB and WG were considered as one village taking the average number of breeding females). Due to long distances between villages for Central Highland (CH), the two villages (Gonder (CH-Gonder) and Ambo (CH-Ambo)) were considered as separate villages bringing the total to four villages for the alternative scenarios.

Breeding goals and selection criteria
Body size was identified as the breeding objective trait for all the three goat breeds. In addition, producers keeping CH indicated twinning and mothering abilities as the most targeted traits to be improved whereas twinning ability and short kidding interval were the most preferred traits by producers keeping WG. Increased milk yield and survivability were the additional targeted breeding objective traits in the case of AB. Selection criteria were six month weight (6mw), average daily milk yield (ADM), survival to six month of age (SURV), litter size at birth (LSB), litter size at weaning (LSW) and kidding interval (KI) for body size, milk yield, survivability, litter size, mothering ability and reproduction performance, respectively. Economic weights for the selection traits were derived according to the procedure illustrated by FAO (2010). The relative importance of selection traits, in an index form, for the goat producers were adopted from reports on productivity studies of same breeds (Tatek et al., 2016).

Description of simulated alternative breeding scenarios
One tier community based breeding practice was taken as the base scenario (SN1) while three alternative scenarios were simulated in this study. The scenarios were; 1) inclusion of dam-side selection to SN1 (SN2), 2) inclusion of genomic selection to SN1 (SN3) and 3) systematic expansion of one tier to the two tier breeding (SN4). In the SN4 scenario, the numbers of additional breeding does targeted were assumed to be about three times the number of does in SN1. Details of the breeding scenarios and other methodologies were indicated in Jembere et al., (2019).

With regard to costs, only additional variable costs were considered (Nitter et al., 1994). The S1Bs that are assumed to be used for mating in additional breeding females in SN4 have been produced through SN1; there may be additional organizational costs but these could not be adequately estimated and thus were assumed to be negligible. On the other hand, additional US$ 125 per animal variable cost (1$ was about 1.0627 EUR on 15th April, 2015) was assumed for pre-genotyping and genotyping in SN3 on top of the variable costs in the SN1. The phenotypic standard deviations were obtained from the respective data generated on the breeds whereas genetic parameters were based on literature review. ZPLANPLUS, a web-based menu driven software (https://service.vit.de/zplanplus/) was used in the present study. The latest version that was used here allows modelling of genomic selection in contrast to the earlier versions.

Results

Predicted genetic gains in breeding objective traits
Predicted annual genetic gains (PAGG) in six month weights (6mw, kg) were highest in SN3 followed by SN2, SN1 and SN4. This was the same for all goat breeds, except for AB where the PAGG in 6mw from SN4 was higher than in SN1 (Table 1). The PAGGs in 6mw ranged from 0.31 to 0.47 for CH-Gonder site, 0.21 to 0.31 for CH-Ambo site, 0.19 to 0.27 for WG and 0.17 to 0.25 for AB. The highest PAGGs in 6mw were obtained for CH-Gonder site, followed by CH-Ambo site; the smallest values for the PAGG in 6mw were for Abergelle goat breed. The same sequence of superiority of PAGG in KI, for Woyto-Guji goat breeds from the scenarios (SN3>SN2>SN1>SN4) as in 6mw, was observed which ranged from 0.17 to 0.42.

While SN3 resulted in the highest PAGG in terms of average daily milk yield (ADM, ml) and in survival rates to six month of age for AB goats, the next highest values were achieved in SN4, followed by SN1 and then SN2. The
PAGG estimated of ADM ranged between 0.62 and 0.97. The overall predicted annual genetic gain of survival rate (%) to three months for AB was generally low ranging from 0.008 to 0.013. Similarly, the predicted annual genetic gains of LSB for CH and WG and LSW for CH were generally small ranging from 0.001 to 0.004. The small predicted annual genetic gains in survival rates to three months of age and the litter sizes at birth and weaning indicated that these traits could not be improved through genetic selection; rather general good husbandry practices could play to the betterment of these traits.

**Predicted monetary genetic gain, discounted profits and Costs**

Highest mGGs, considering all the scenarios, were realized from Abergelle followed by Woyto-Guji, Central Highland Ambo site and Central Highland Gonder: the values ranged from 0.07 to 0.09 for Abergelle, from 0.07 to 0.09 for Woyto-Guji, 0.06 to 0.08 for Central Highland Ambo site and 0.05 to 0.08 for Central Highland Gonder site. Due to the relatively high costs, the discounted profit from SN3 was negative for all breeds in all sites. Positive profits were obtained from the three other scenarios except from SN1 for Woyto-Guji goat breed. SN4 resulted in the highest profits, followed by SN2 for three sites while the profit from SN2 was higher than from SN4 for Central Highland Ambo site. Breeding programs for Abergelle were more profitable than for the other goat breeds and sites, while the smallest profits were achieved with WG. The values (Euro) for profitable scenarios ranged from 0.13 to 0.35 for AB, from 0.05 to 0.1 for CH Ambo, from 0.04 to 0.16 for CH Gonder and from 0.01 to 0.17.

**Table 1:** Predicted annual genetic gains (PAGG) in selection traits, generation interval (GI) and intensity of selection (IS) from the four scenarios (SN) for Abergelle (AB), Central highland (CH) and Woyto-Guji (WG) goat breeds in Ethiopia

<table>
<thead>
<tr>
<th>Trait*</th>
<th>SN1</th>
<th>SN2</th>
<th>SN3</th>
<th>SN4</th>
<th>SN1</th>
<th>SN2</th>
<th>SN3</th>
<th>SN4</th>
<th>SN1</th>
<th>SN2</th>
<th>SN3</th>
<th>SN4</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mw</td>
<td>0.17</td>
<td>0.18</td>
<td>0.25</td>
<td>0.18</td>
<td>0.34</td>
<td>0.36</td>
<td>0.47</td>
<td>0.31</td>
<td>0.23</td>
<td>0.24</td>
<td>0.31</td>
<td>0.21</td>
</tr>
<tr>
<td>ADM</td>
<td>0.74</td>
<td>0.62</td>
<td>0.97</td>
<td>0.87</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KI</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.27</td>
<td>0.19</td>
<td>0.17</td>
<td>0.42</td>
</tr>
<tr>
<td>Pro(€)</td>
<td>0.13</td>
<td>0.26</td>
<td>-8.6</td>
<td>0.35</td>
<td>0.04</td>
<td>0.08</td>
<td>12.8</td>
<td>0.16</td>
<td>0.05</td>
<td>0.10</td>
<td>13.4</td>
<td>0.06</td>
</tr>
</tbody>
</table>

6mw=PAGG in six month weight (kg); ADM= PAGG in average daily milk yield (ml); KI=PAGG in kidding interval (days); Pro(€) = profitability in EURO. * the Pro(€) in SN3s and SN1 of Konso site were negative.

**Discussion**

All the three scenarios simulated as alternatives to the current CBBP of goats in Ethiopia had advantages in terms of PAGG over the baseline CBBP in all the three breeds. Sizable PAGG, however, were obtained for 6mw weight only. The other breeding objective traits did not show substantial predicted annual genetic gain. This is probably because of generally low levels of variability for the traits within each of the populations. Heritability values of twining, mothering ability and survivability were smaller compared to the growth traits (Safari et al., 2005; Jembere et al., 2017). The unfavourable genetic correlations of these traits with growth traits could also be another possible reason for small genetic gain realized in the rest traits compared to growth. Abegaz et al., (2014) reported PAGG in 6mw (kg) of 0.8702 to 0.8724 and 0.360 to 0.365 for Western lowland part of Ethiopia and AB goat breads, respectively. These authors also reported PAGG in average daily milk yield (kg) for AB breed to be 0.0066 to 0.0114. These values were higher than the ranges of PAGG in 6mw in the three breeds and ADM in AB goat breed predicted from the current study. Except for Abegaz et al., (2014), reports for such comparisons were not available on indigenous goat breeds of Ethiopia.

However, similar reports are available on sheep breeds in Ethiopia and elsewhere. Gizaw et al., (2014) reported PAGG of 0.119 to 0.286 kg in 6mw of Menz sheep which is in agreement with this study from the various scenarios except for the higher value reported from the central highland Gonder site. However, simulations by Mirkena et al., (2012) resulted in much higher values of PAGG in yearling weights for Ethiopian sheep. The values in kg were in the range of 0.813 to 0.894 for Bonga, 0.850 to 0.940 for Horro and from 0.616 to 0.699 for Menz.
Conclusion
Based on the PAGGs and profitability we suggest SN2 over SN1. However, SN4 could also be applied, compared to SN1, in view of higher profitability and suitability of addressing emerging demands. The PAGGs in reproduction, mothering ability and survival were small implying that improvements of these traits are best achieved through improved management levels as part of the overall improvement program.

Acknowledgements
We are thankful to the partner research centers namely Tanqua Abergelle, Sekota Dry land, Gonder and Arbaminch for their close follow-up of data collection.

References


THEME 6: PASTORALISM, SOCIAL GENDER AND POLICY ISSUES

Topic: Governance, Investment, Infrastructure and Markets
Perceptions on governance for effective adaptation to climate change within community-based wildlife conservancies in Kenya

Kibet, S.¹ and Wasonga, O.V.¹

¹Department of Land Resource Management and Agricultural Technology. University of Nairobi

Key words: [Access to pasture and water; livestock mobility; wildlife conservation]

Abstract
Community-based wildlife conservancies (CBC) represent a broad spectrum of new management arrangements and benefit sharing partnerships in natural resource management by none state agents, but who, by virtue of their collective location and activities, are critically placed to shape the present and future status of these resources. This approach of wildlife management is increasingly gaining popularity as an option for achieving sustainable co-existence and complementarity between wildlife conservation and livestock production in the drylands of Kenya. Despite difference in ownership and governance structure in place, all conservancies have instituted new rules of control and access. This study sought to understand whether the governance system promoted inclusivity among the various social groups and secondly whether or not the model promotes enhancement of household resilience. Quantitative and Qualitative data based on household surveys, focus groups discussions and Key informants’ interviews were collected in two counties of Samburu and Isiolo and subjected to Q1Macros for descriptive analysis. The CBCs are governed by a board, supported by sub-committees. The board provide leadership and oversight and ensures transparency, adherence to the law, and equitable representation and sharing of revenue. Women representation in the boards recommended, and almost compulsory in Northern Rangeland Trust (NRT) supported conservancies. Broadly, household’s social amenities as health facilities, bursaries for school going children, and access to credits have improved under CBC. Movement of livestock between conservancies in search of pastures and water during drought is managed through grazing committees but is not effective during times of prolonged droughts. Traditional system based on the value of reciprocity, is eroding with the creation of new forms of resource management where others may be excluded. Simmering mistrust amongst neighbouring pastoral communities is common. Reciprocity for water and pastures within and between communities and within neighbouring Counties must be factored in CBC implementation plan.

Introduction
Community Conservation (CC) or Indigenous Community Conservation Areas (ICCAs) or Community based Conservancies (CBC) represent a broad spectrum of new management arrangements and benefit sharing partnerships for the involvement in natural resource management of people who are not agents of the state, but who, by virtue of their collective location and activities, are critically placed to shape the present and future status of these resources, so as to enhance their conservation and the well-being of local communities (Barrow and Murphree, 1998). Conservancies are defined by World Parks Congress as private protected areas (Goriup 2005). The CBC model is a counter-narrative that promises to reconcile conservation and development objectives, and ensure the interests of the local people are taken into account. It is based on three pillars; benefit, empowerment, and conservation (Barrow and Murphree 2000; Murphree 2009; Dressler et al., 2010). As a natural resource management approach that allows communities to manage and benefits from wildlife resources it has been a subject for research in the last two decades. Earlier studies focused on principles and practice behind approach and policy (DeGeorges and Reilly 2009; Barrow et al 2000; Barrow and Murphree 2001) however in the recent past perhaps due to existence of a number of CBC for more than a decade, focused have shifted to design and implementation (Keane et al 2016;
Kicheleri et al 2019), evaluating effectiveness to deliver conservation and development objectives (Mariki, 2019; Measham and Lumbasi, 2013; Glew et al 2010), as well as social and ecological impacts (Oduor, 2020; Mureithi et al 2019; Pas 2018). The extent to which these twin objectives have been realized is a subject of debate. There are mixed reports with some success stories (Mureithi et al., 2019; KWCA, 2016) as well as failures (Mariki, 2019; Simasiku et al 2008) on attainment of intended objectives.

What is clear however is that the popularity of CBC continues to grow in the Africa region especially in Kenya. As at 2016, there were 160 conservancies in Kenya, 76 of which were Community Conservancies and 26 were Group Conservancies, others were private Conservancies. Cumulatively they were managing land of about 6.4 Million ha (approx. 11% of total Kenya’s landmass) spread across 28 counties and new entries are expected (KWCA, 2019). It has been observed that establishment of CBC has been accompanied by rules and regulations that have compromised resilient pastoral livelihood strategies such as livestock mobility (Pas, 2018; Bedelian and Ogutu 2017). Despite increasing popularity of the system, there is paucity of knowledge on the how accompanying changes in governance in view of climate change affect the intended outcomes. This study therefore sought to investigate whether the CBC governance system promote inclusivity among various social groups and secondly whether or not the CBC promotes enhancement of community resilience through effective adaptation to climate change.

**Governance**

Governance is the manner in which power is exercised in the management of a country’s/ community’s ecological, social and economic resources for development (ADK, 2005). Whereas linkages between the functioning of governance and notable improvement in people’s lives may not be obvious, both practitioners and academics agree that many determinants of household’s ability to cope with stress, seize opportunities and invest in their future are intimately linked to governance outcomes (USAID, 2014). Good governance has been fronted as being participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive and follows rule of law (UNESCAP, 2009). These attributes form the basis for the study.

**Adaptation and resilience building**

Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts or changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (UNFCCC website). Climate change affects ecosystems and social systems in unpredictable ways and therefore it is best tackled in multi-disciplinary ways through different knowledge systems with participatory practices that enable learning (USAID, 2014).

**Methods and Study Site**

We did a review of literature from across Africa combined with a case study in two CBC in northern Kenya. We searched for published and grey literature on subjects as community-based conservation, community based natural resource management, Indigenous community and conservation, community-based conservancies, and community wildlife conservancies using google search engine, Web of science and springelink.

In addition, we collected both qualitative and quantitative data primary data. We used open ended questionnaire, participant’s observations and focus group discussions (FGD) to collect qualitative data, while household surveys and Key Informants Interviews was used to gather quantitative data. Stratified random sampling was adopted to select informants. Sampling was stratified by villages and randomized within the villages. Data collection was done for six months scattered between 2017, 2018 and 2019 in Samburu, Isiolo, and Laikipia Counties. Pastoralist communities from Counties of Samburu and Isiolo were targeted. Kalama and Nasuulu Community Wildlife Conservancies in Samburu and Isiolo Counties respectively were selected for in-depth study. The two were selected based on long-term experience and governance structure dynamics.

In total we interviewed 115 people; 65 men and 50 women of different ages from among members and non-members of the conservancies. We also conducted 11 focus group discussions; 6 in Samburu and 5 in Isiolo Counties. Each FGD consisted of 4-6 persons, separated by gender (men and women) except among the peri-urban Borana community where joined FGD was conducted. Interviews were conducted by field assistants using local dialects, Kiswahili and English depending on the target group and immediately translated as necessary. Data was later coded according to the topics and analysis was done using Q1 Macros (KnowWare International Inc. 1996-2014). We assessed resilience building based on USU-IAS, Bioversity International, IGES and UNDP (2014) resilience indicators toolkit based on whether or
not CBC facilitate (1) access to heterogeneous landscapes that provide greater biodiversity and ecosystem services; (2) integration of knowledge and innovations, (3) governance and social justice and lastly (4) livelihood and wellbeing.

**Study Area**

Samburu and Isiolo Counties where this study was done falls within arid and semi-arid lands of the greater 83,000 Km$^2$ of Ewaso Ng'iro catchment that stretches from the slopes of Mt. Kenya to Moyale in the north and Garissa in the East. Ewaso Ng'iro River that derives its water from Mt. Kenya and Aberdares ranges separate the two counties (figure 1).

**Figure 1**: Map of Ewaso Ng'iro Catchment in northern Kenya showing the study sites – orange dots (Adopted from Ericksen et al., 2012).

**Results and Discussions**

Paradigm shift from state-driven protectionism (Fortress conservation) strategies to community-driven conservation in natural resources management has been rising as a dominant discourse based on experiences in East and Southern Africa in the 1970s and 1980s. The CBC has continued to grow despite doubts being raised concerning their effectiveness to achieve conservation and development goals.

**Governance**

Perhaps due to the complexity and wooliness of the term community, some Community Conservancies have been implemented successfully while others have encountered many challenges despite similarity in their approach. Inclusion of women in the Conservancy boards and youth in the grazing committees have been highlighted as one major achievement in the governance structure of the CBC particularly those under Northern Rangeland Trust (NRT). This strategy seemed to have motivated the women and some men alike. The level of vibrancy due to women participation was palpable in Kalama Conservancy. During focus group discussion, one woman quipped:

“Nowadays women are busy with development matters for the community and they have left gossiping to men” Respondent 13.

Resource use regulation and enforcement, regular meetings and access to natural resources was also indicated as a success stories by CBC members. Incorporation of traditional institutions as part of decision-making organs benefits from indigenous/local knowledge. This support knowledge integration and innovation as expounded USU-IAS, Bioversity International, IGES and UNDP (2014).

Governance in multi-ethnic owned Conservancies seemed strained compared to single ethnic owned CBC despite regular meetings and elections. Tensions among communities emanate from among others (1) Strong held position that they are the rightful land owners and that others were co-opted to buy peace (2) That there is no equity nor equality in the sharing of benefits. The use of quota system often used is perceived to be biased and advantageous to communities with smaller population (3) perceived skewed representation in conservancy boards, grazing committees and even employment opportunities shared based on ethnic composition irrespective of population size. Absence of identification cards does not make it any easier given fluidity of membership. Claims of non-members benefitting from CBC resources have been reported. An example was quota system NRT Trading used to buy cattle from Conservancy members as a means to destock during drought. Communities who did not have adequate numbers are claimed to have purchased cattle in Isiolo market and resell them to NRT Trading due to premium prices offered. This action denied members who were willing to destock more of their livestock to do so.

Cases of exclusion have also been reported where establishment of CBC led to a tenure system arrangement that allow certain parties and excluded others (Kibet, 2019; Pas, 2018; Grainer, 2012; CDC et al 2009) and this has been source of tension and often violent conflicts. In CBC owned wholly by one ethnic community, reported elite capture, bungled elections, and elements of
corruption in benefits sharing are some of the challenges in its governance system as pointed out by a female respondent who had recently been elected to office in Kalama Conservancy.

“As a subcommittee mandated to manage the disbursement of bursaries not a single complain has been raised in the last two years they have been in charge, unlike previous years when there were many members complained. I don’t understand where the money has been disappearing to in the previous years”. Respondent No. 18. She went ahead to highlight key projects they have been able to support on health and education.

The exercise of power and authority by those elected into Conservancy boards and grazing committee were ineffective during times of prolonged drought. During these time, collective actions as CBC community is greatly compromised as more of individualization of decision and actions takes root. Often at such times long distance livestock mobility (sometimes several hundreds of kilometres) far beyond the conservancy boundaries is witnessed. Cases of blatant disregard for bylaws by herders are also common at such times (Pas 2018).

The CBC governance system is viewed with suspicion by non-members whether or not non-members belong to same ethnic group as members or not. Enforcing rules and regulations under CBC deprive non-members access to previously accessible resources. For example, communities living within the suburbs of Isiolo town who previously made a living by making charcoal from Lepara and Nasuulu community conservancies had no kind words for the changed status. Occasional illegal charcoal making occurs in the two conservancies.

There has been simmering mistrust amongst neighbouring pastoral communities in Isiolo County since armed Conservancy Rangers/scouts were introduced to enforce CBC land use regulations.

Adaptation and resilience

Good governance espouses effective participation, inclusivity, consensus building, representation and equitable sharing of benefits. Good governance strengthens community adaptive capacity and resilience to shocks and stress. The NRT which currently coordinate 39 CBC across 10 Counties, indicated that as at 2019, 20% of board members, 8% of conservancy managers, 6% of Scouts and 5% of Rangeland coordinators were women (NRT, 2019). In the two conservancies we studied, there were 3 and 4 women in Kalama and Nasuulu 13 and 16 member-boards respectively.

Effective and efficient representation, and equity in benefit sharing is still a challenge particularly among multi-ethnic owned CBC and does not help in building effective adaptation. During our fieldwork in Nasuulu Community Conservancy, the research team noted presence of camels browsing in an area preserved for dry season grazing. It later emerged that a non-member had been allowed access by relatives who are members of the conservancy contrary to grazing by-laws. Absence of identification marks makes it extremely difficult to separate members from non-members’ livestock.

Large tracts of land have been invaded by Acacia reficiens (Olchurai in Samburu) rendering them bushlands with low grazing capacity even during years with good rains. Active removal of invader species (Acacia reficiens), controlled grazing, creation of core conservation areas and ban on charcoal making in Kalama and Nasuulu Conservancies constitutes ecological impacts of CBC governance. Controlled grazing and weed removal promote increase in both plants and animal’s species diversity and ultimately ecosystem services.

The expectation to earn income from tourism has not been realistic in a number of Conservancies due to varied challenges. Kaptuiya and RUKO Conservancies located in Baringo County, for example, have hardly receive any meaningful number of tourists since their establishment mainly due to insecurity concerns (Grainer, 2012). Similarly, Nasuulu and Leparua Conservancies based in Isiolo County continues to rely 100% on NRT funding support to run its operations and this raises a question of their sustainability in absence of donor funds. It however true that some CBC have made significant development from utilizing their natural resources such as Namunyak, Kalama, Il Ngwesi and Sera in northern Kenya. NRT reported Kshs. 133 Million (US$ 1.33 Million) revenue mainly from tourism that accrued to CBCs (NRT, 2019).

Most CBC under NRT have continued to diversify sources of income for their members through sales of goods and services such as livestock and beadwork through NRT Trading and businesses ventures. Access to microfinancing from Nabulu Saving Scheme and The Northern Rangeland Savings and Credit Cooperative (NR SACCQ) have made it easy to access start-up capital. Direct benefits to individuals are reviving hope for those who had lost their livelihoods from lost livestock or ban of charcoal making. One respondent from Nasuulu Conservancy could not hide her joy.
“We are fortunate my son got sacco loan. He bought a motorbike he uses for transport business and this has helped a lot during the dry season when there is no milk. We use the money from the business to buy milk in Isiolo town” (Respondent No. 7)

Livelihood diversification is thought to promote community ability to adapt to shocks (Wan et al., 2016; Lenaiyasa et al., 2020). Availability of affordable transport and access to medical services in was rated highly in Kalama and Nasuulu Conservancies. In an area with poor roads, transport for sick people is a big challenge. The prospect of owning a conservancy vehicle carried the day when Girigiri Group Ranch members were deliberating on the establishment of Kalama Conservancy. One respondent recall,

“When Lewa Conservancy boss came to inform the elders about benefits of a Conservancy, Namunyak had established their own some 2-3 years earlier. Around that time there was an outbreak of a disease and the Namunyak vehicle was so hardy in transporting sick people to hospital. We all admired them and we agree to start our own Conservancy” (Respondent No. 12)

Other benefits thought to boost community adaptation to climate change reported include access to bursaries for education, employment opportunities, and access to schools by children, and water for domestic and livestock. USU-IAS, et al., (2014) recognizes that efficient and functioning infrastructure such as communication, health, and education together with availability of opportunities to engage in sustainable income generating activities greatly support communities’ resilience to shocks.

Strong views on enhancement of peace and security under CBC was central during focus group discussion among members of Turkana community from Nasuulu Conservancy. They stated that CBC has brought peace in the valley. Violent conflicts between Turkana and Samburu and/or Borana and/or Somali over access to water and pastures were a common occurrence during times of drought. In 2012 for example, fight broke out between members of the Turkana and Somali communities, with some Borana involvement. This was triggered by unattended camels that trespassed into people farms, and forage on food crops, reserve pastures, and live fences during time of time of migration. At least 10 died and over 2,000 people were displaced (Safeworld, 2015). One major responsibility of NRT council of elders (made up of all chairpersons elected on members CBC) is to broker peace and security in the region. Wherever applicable, adaptation to climate change must be informed by conflict prevention and peacebuilding efforts. Reciprocity during time of drought among pastoralists remain strong social capital that seem to have be weaken by CBC governance due to exclusion rules and regulations.

Besides governance related issues, human-wildlife conflicts and livestock preventive healthcare have yet to be fully addressed. Some CBC members raised concern that with successes in wildlife conservation, human-wildlife is likely to increase and may lose their livestock/crops or even lives. During our visit to Kenya Wildlife Services offices in Isiolo county, the research team witnessed a widow making a compensation claim having lost all 18 goats she had to hyenas. The officer in charged informed us that approximately 700 claims are filed every month in Isiolo office alone. The process of reporting and verification is long and tedious; unfortunately, actual compensation is slow due to financial constraints on the government. As at 2018, the last time compensation was done was in 2013.

Conclusion
Community based Conservancy (CBC) has been widely marketed in Kenya and the World at large as an answer to natural resource conservation and livelihoods development needs for rural communities. Significant success has been witnessed in attainment of conservation needs, however, livelihood development is subject to debate. The CBC in the country have made significant contribution towards promoting wildlife and rangeland conservation and more are being established. Perceptions on CBC governance structure is mixed both amongst members and non-members alike. Incorporation of women and youth in decision making organs of CBC has been hailed as innovative, however perception of skewed representation, lack of accountability and absence of equity in sharing of benefits remains source of disillusionment. CBC governance structure supports tenets necessary for communities to build their resilience against shocks and stress such as impacts of climate change. This includes promotion of income diversification, sustainable enterprises based on local resources, enhancement of livelihood and wellbeing. However, weakening of social capital such as reciprocity compromises adaptation.
• There is need for each conservancy to brand their livestock with unique marks for ease of identification of non-members livestock grazing on the conservancy, as well as identifying ‘genuine stock’ during offtake by NRT Trading.

• Due to challenges that may arise with possible increase in wildlife populations, livestock disease preventive health plan is necessary so that their co-existence may not be strained. Equally important is improvement in the implementation of wildlife on human-wildlife conflicts compensation.

• Reciprocity for water and pastures within and between communities as well as neighbouring Counties must be factored in areas planning to implement CWC model to support landscape thinking.

Acknowledgement
This study was made possible with financial support from Adaptation at Scale for Semi-arid Regions (ASSAR) for which we are grateful. We acknowledged support from Jacob Olonde during field data collection and the communities of Kalama and Nasuulu who were kind to share with us their knowledge.

References
USU-IAS, Bioversity International, IGES and UNDP 2014. Toolkit for the Indicators of Resilience in Socio-ecological Production Landscapes and Seascapes (SEPLS)


Climate Change Policy Narratives and Pastoralist Predicaments in the Horn of Africa: Insights from Ethiopia and Kenya

Campbell, T.

Department of International Development, Maynooth University E: tom.campbell@mu.ie

Key words: pastoralism, climate change, policy narratives, livelihoods, governance.

Abstract
Drawing on the findings of a two-country case study, this paper examines the discourses and narratives found in contemporary climate change and national development policy in Ethiopia and Kenya, the actors shaping those policy narratives, and in turn, their consequences for pastoralism. The research reveals that while concerns around climate change and calls for strengthening resilience of dryland communities have given a new impetus to pastoral development, old arguments and assumptions that depict pastoral areas, and pastoralists, as unproductive and in need of modernisation remain deeply embedded in policy making. These open up spaces for the state, investors, and local elites to extend control over natural resources previously managed under customary institutions. The resultant climate policy solutions and dryland investments are, in turn, leading to new patterns of social differentiation and vulnerability among pastoralists. Clearer overarching national land-use policies that integrate principles of ‘pastoral area governance’, and that put measures in place to prevent the further loss of key pastoral resources would make a difference in terms of enhancing pastoralists’ rights and livelihoods.

Introduction
While there is a growing body of knowledge on the effects of climatic and other forms of change on pastoralism in Africa, less is known about how recent policy responses and development interventions in the name of climate change, or drylands development, in the Horn of Africa (HoA), are shaped by certain discourses and narratives, and what the outcomes of the prescriptions and decisions that flow from policy narratives are for pastoralist communities. Studies to date have focused on, for example: the persistence of drylands narratives (Odhiambo, 2014); the influence of global climate change narratives on agricultural policy including pastoralism in Kenya and Ethiopia (Maina et al., 2013; Yirgu et al., 2013); localised climate adaptation interventions in pastoral areas in Ethiopia (Erickson and Marin, 2015); or on green economy discourses and the role of the state (Jones and Carabine, 2013; Death, 2015). These (and earlier) studies point to the fact that, for decades, dominant dryland narratives of ‘tragedy of the commons’, ‘desertification’ and ‘overgrazing’ underpinned conventional pastoral-development policies and did little to strengthen pastoralist livelihoods. At worst, they led to displacement and marginalisation (Fratkin, 1997; Little et al., 2008; Catley et al., 2013; Abbink et al., 2014). In recent years, the state and their development partners have sought to respond to regional concerns about climate change, food security and political security. It has been suggested that while the language may have evolved, some of the narratives driving current climate-change and green-economy policies in Ethiopia and Kenya are not necessarily ‘new’, but are instead rooted in historical discourses around ‘unproductive’ drylands and the need for modernisation (Odhiambo, 2014; Krätli, 2019). Policies, furthermore, do not cause outcomes in a linear fashion. The kinds of changes underway in pastoral areas are driven as much by demographic growth, changes in market supply and demand, and regional security concerns, as they are by policymaking and political processes. Growing urban settlements, new roads, renewable energy projects, oil and mineral extraction – even wildlife conservancies – are increasingly linked

1 For a history of dominant dryland narratives in the HoA, see also: Swift, 1996; Fratkin, 1997; Little et al., 2008).
in a modernist vision of economic and social transformation (Mosley and Watson, 2016; Lind et al., 2020). Combined, these factors have profound implications for the future of pastoralism, as large expanses of grazing land are no longer accessible, and mobility – pastoralists’ key strategy for managing variability – is restricted. Yet these developments are generally perceived by policymakers as part of a wider – and necessary – dynamic of commercialisation and (green) growth, and even as a precursor to enhancing climate-resilient livelihoods “outside of pastoralism” (Kräti, 2019: 12).

Methods

This paper is drawn from the findings of a Doctoral research project, done by the author between 2016 and 2020. The study employed a comparative case study approach composed of two macro-units of analysis (Ethiopia and Kenya), using content analysis (CA) and discourse analysis (DA) (Hajer, 2006) of relevant national climate change, agricultural and economic development policy documents (17 in the case of Ethiopia, 16 from Kenya, from the period 2007-2017), supplemented with data drawn from interviews with 68 key informants in the two countries. Care was taken to identify and select informants from a range of policy actors, sectors and perspectives.

Ethiopia and Kenya were intentionally selected as they have much in common but also have quite different political and historical contexts. Both are prominent adoptees of policies favored as part of the new international consensus around ‘green development’ and climate change (Death, 2015). They share similar dryland zones, with significant populations who identify themselves as pastoralists, or agro-pastoralists. Both have been considered relatively successful in economic development terms, yet are experiencing similar development and climatic challenges. In recent years, Ethiopia and Kenya, like other countries in the HoA, have both seen increased frequency and severity of drought – albeit with impacts and consequences that are site-specific, varied, and uncertain.

Results

The CA and DA of policy documents revealed that despite new thinking around the inherent resilience and adaptive nature of pastoralism, a ‘transforming pastoralism and the drylands’ discourse remains dominant in both cases, if slightly less so in Kenya. Within this discourse, often simplistic and depoliticised environmental crisis narratives of ‘unproductive and conflict-ridden’ drylands and ‘climate-induced pastoralist vulnerability’ remain to the fore. Arguably, such simplifications are convenient for policymakers in that they help generate consensus and make action possible in the face of uncertainty (Roe, 1991). They also amplify the perception that some kind of ‘intervention’ needs to take place, so opening up space for the state, or other actors, to gain greater control over land and other resources previously managed under customary institutions. If drylands are perceived – or deliberately framed - as somehow ‘empty’ or ‘unproductive’ then it follows that conversion to other forms of land use – irrigated cropping, resource extraction, wildlife conservation – is justifiable. In both cases, it is apparent that the desire to ‘transform’, ‘commercialise’ and ‘integrate’ dryland resources - including the pastoralist economy - within a broader framework of national development, is being driven by an ideology of market-based economic growth and modernisation, notwithstanding a strong mediation role for the central state. The imperative of climate change, meanwhile, has provided a new language to policymakers to reframe growth as an opportunity to build a ‘green economy’ and to redefine the role of the state (Death, 2016). At the same time, the analysis reveals a higher level of interdiscursivity within the Kenyan policy documents reviewed – reflective of the more open and participatory nature of Kenyan policymaking, but also of the fact that a conducive ‘policy space’ for pastoralists to engage in Kenyan politics opened up at a particular point in time: notably the formation of the Ministry for Development of Northern Kenya and Other Aid Lands (MDNKOAL) in 2008, the subsequent ‘ASAL Policy’ (2012), and the process of political devolution underway since 2012.

Interviews in turn revealed that government actors in both Ethiopia and Kenya (but especially in Ethiopia) were more likely to frame contemporary challenge facing pastoral areas in terms of a naturalistic understanding of vulnerability and the causes of conflict, while prescribing largely technocratic solutions – broadly matching the dominant ‘transforming pastoralism’ discourse found in the document analysis. Non-state actors, utilising metaphors and narratives more usually associated with ‘pure pastoralist’ and ‘modern and mobile’ (de Jode, 2010) discourses (that holds that mobile pastoralism is the most ecologically and economically appropriate form of land use in dryland areas, and which highlights pastoralists as innovators) pointed instead towards the appropriation of rangeland resources as undermining pastoralist’s inherent adaptive
capacity. Nonetheless, state actors in both cases have clearly adopted the language of counter narratives – as they seek to mobilise resources around common goals of ‘climate resilience’, food security and economic growth. Giving credence to the assertion that narratives shift to suit the needs of actors as new opportunities and contexts arise (Whitfield, 2016). While pastoralism may no longer be considered as ‘backward’ or the antithesis to the modern state, and the language of ‘resilience’ has been adopted as a means to rationalise government mediated development interventions, there is a sense that the state in Ethiopia is using climate change to validate the continuation of past unpopular policies which may actually exacerbate vulnerability – such as sedentarisation, or the displacement of pastoralists from key resources. Nonetheless, the influence of donors, of United Nations (UN) agencies - and to a lesser extent, a select group of International non-governmental organisations (INGOs) and individual drylands researchers - on shaping current narratives, and bringing elements of the ‘pure pastoralism’ and ‘modern and mobile’ discourses to debates on the future of pastoralism is significant. Donors clearly have the financial resources and close links to government departments to be able to influence some polices, especially those focused on ‘resilience building’ or rangeland management. Civil society organisation (CSO) informants: to a lesser extent. In Kenya, in contrast, considerable discursive commonality was identified within the responses of Kenyan informants. While there was consensus that climate change is just one of a number of stressors currently driving pastoralist vulnerability, there was some difference in where causality for these challenges was placed, and the extent to which pastoralists are either taking advantage of, or being pushed aside by, the changes underway. Here too, government officials have clearly absorbed the kind of narratives and metaphors associated with a ‘modern and mobile’ discourse, while also retaining certain perspectives in line with the ‘transforming’ discourse that was to the fore in most policies analysed. Ultimately, the Kenyan government is motivated by the desire to transform and integrate it’s dryland resources and production within a broader vision of national economic development set out in Vision 2030. While the state is the dominant actor driving national policy narratives it is not the only influential actor. NGOs, researchers, UN agencies, and even certain CSOs, form part of a ‘discursive coalition’ (Hajer, 2006) of like-minded actors who have brought about a noticeable paradigm shift in thinking around pastoralism – a shift that is beginning to be reflected in the rhetoric, if not necessarily in all areas of policy implementation. Data from interviews broadly supported what has been argued by a number of scholars elsewhere: that the kinds of policy prescriptions and planning that flow from dominant narratives surrounding climate change, the ‘green economy’ and the development of pastoral areas more generally primarily serve the interests of those who have most to gain from greater commercialisation, changes in land use and the privatisation of formerly communally managed resources. In Ethiopia, this includes the state itself - in terms of higher economic growth (the benefits of which are arguably being reinvested in rural development and improved services) - but also private investors and a growing commercial and politically well-connected class within pastoralism. Technocratic solutions and control-orientated measures – programmes of sedentarisation, fixed waterpoints and conversion of dry-season pastoral reserves to crop cultivation – continue to be prioritised by the state, despite a long history of similarly ill-fated interventions. As a result, communities along the Awash River (Afar) for example, or minority indigenous agropastoralist groups, such as those in the Lower Omo Valley, face enforced villagisation and subsequently find themselves more vulnerable, or even destitute as a consequence. Similarly, narratives of ‘green growth’, ‘food security’ and ‘climate resilience’ are being evoked by policymakers in Kenya as a means of legitimising new infrastructure projects and private investments in arid and semiarid land (ASAL) counties. While infrastructure development corridors, such as LAPSSET, the rapid growth in towns, investments in extractives, green-energy projects (Lake Turkana Wind Power), irrigated cropping - even wildlife conservancies - bring gains for some others are ‘losing out’ as a consequence. As in Ethiopia an emergent local elite (including large herd owners and ex-pastoralists) has been able to use their political connections at both national and county level to capture the benefits of devolved power and resources, or have managed to profit from compensatory payments for infrastructure development and changes in land tenure. At risk of falling into destitution are those less asset-rich households and/or minority groups that face new forms of displacement in the name of green economic growth or conservation, or as political boundaries are redrawn along ethnic lines. Such groups are less equipped to deal with climatic ‘shocks’ when they do occur. There are some differences nonetheless. The study found that there is a stronger coherence between various climate-adaptation and drought-management strategies in Kenya. Under the 2016 Climate Change Act, all such policies and plans must be channelled and

3 Lamu Port South Sudan Ethiopia Transport Corridor
mainstreamed through devolved government, so (in theory) opening up more space for community engagement in decision-making. In Ethiopia different ministries are more likely to work separately on different policies, often competing for donor support. In Kenya, while many pastoralists suffer the consequences of rangeland fragmentation and inappropriate development, they are not subject to any official sedentarisation policy (as in Ethiopia) – nor would they accept such an imposition, given their stronger political power. In Kenya, local communities have shown they have the power to resist unwelcome forms of development, in a way that has not been permitted in Ethiopia until very recently. In Kenya, the 2016 Community Land Act (CLA) is generally welcomed as offering a progressive means by which communal land holding can be legally recognised and pastoralist tenure protected. No such similar legislation exists in Ethiopia.

Conclusions

This paper argues that policies and interventions in the name of climate-change adaptation and pastoralist development need to be considered within the context of political interests and governance in pastoral areas. Climate-adaptation and resilience-building types of policies and programming on their own, whether well-intentioned, or, as we have heard, designed with other interests and priorities in mind, are clearly insufficient to address the multiple challenges faced by pastoralists in the HoA. ‘Governance’ opens up a broader political agenda that addresses the political processes and relationships through which state and non-state actors interact, allowing policymaking in the HoA to move beyond the kinds of depoliticised ‘environmental-crises’ narratives that are a feature of the ‘transforming pastoralism’ discourse described above. It is evident that clearer overarching national land-use policies that integrate principles of ‘pastoral area governance’, and that put measures in place to prevent the loss of further key pastoral resources would make a difference in terms of enhancing pastoralists’ rights and livelihoods. At the heart of such governance is the need to facilitate, rather than impede, mobility – pastoralists’ primary means of managing variability. There is a need, furthermore, to safeguard strategic resources from inappropriate forms of capital accumulation – investments frequently driven by the very policies that purport to transform pastoral areas in the name of ‘green growth’ or ‘climate resilience’. The extent to which poorer pastoralists will be able to adapt to environmental, economic and political change, and take advantage of policy initiatives and economic opportunities – in a manner that is both equitable and sustainable – depends on how willing the state is (with or without the support of development partners), at both national and local government levels, to create an enabling space for responsive and inclusive governance in pastoral rangelands.

References


Large scale land investments and food security in agro-pastoral areas of Ethiopia

Bekele, A.E.;1,2, Dries, L.;2, Heijman, W.2,3 and Drabik, D. 2

1Department of Rural Development & Agricultural Extension, College of Agriculture and Veterinary Medicine Jimma University, Jimma, Ethiopia
2Department of Social Sciences, Agricultural Economics & Rural Policy Group, Wageningen University & Research, Wageningen, the Netherlands
3Department of Economics, Czech University of Life Sciences Prague, Czech Republic.
Email: adugna_e@yahoo.com or adugna.bekele@wur.nl

Abstract
There is an ongoing debate about the impact of large scale land investments on the livelihoods of rural households in developing countries. This study investigates the impact of large scale land investments on households’ food security in Ethiopia. The findings show proximity to large scale land investments is associated with higher food intake with an average treatment effect of 744.71 kcal per day per adult. This is mainly because of the availability relatively good natural capitals near to large scale land investments. Large scale land investments should make sure that the local community has access to grazing to improve food security of the local communities.

Key words: Food security, large scale land investment, sugar plantations, livelihoods, pastoralism, propensity score matching

Introduction
Pastoralism and agro-pastoralism are predominant production systems in the arid and semi-arid drylands of Africa. About 25 million pastoralists and 200 million agro-pastoralists live in Sub-Saharan Africa (SNV, 2012). Pastoralists mainly depend on livestock production, while agro-pastoralists depend on livestock and crop production for their livelihoods. Ethiopia has one of the largest (agro-) pastoralist areas in East Africa, covering 61% of its drylands. Livestock contributes to the livelihoods of 60% - 70% of the Ethiopian population (Halderman, 2004). The country also has the largest livestock population on the African continent (FDRE, 2014). Despite this considerable livestock resource, Ethiopia is one of the most food-insecure countries in the world.

The Growth and Transformation Plan of Ethiopia aspires to make the country a lower middle-income country by 2025. It considers large scale land investments (LSLIs) to be a vital tool for developing the pastoral areas (Keeley, 2014). With these investments, lands with good pasture, water, and wildlife were taken to state-owned and private farms. The impact of LSLI on household food security in Ethiopia is, however, not yet fully understood. Therefore this paper provides an insight into the impact of proximity to LSLI on pastoral household food security, one of the most debated issues.

Data and sampling
We used data from the Living Standard Measurement Survey (LSMS) for Ethiopia for the years 2011/12, 2013/14, and 2015/16. The LSMS is a Rural Socio-Economic Survey from a collaborative project between the Central Statistical Agency of Ethiopia and the World Bank (CSA, 2017). We include 12 zones of major agropastoral regions in our study: Jigjiga, Liben, and Shinile, Afar zone 1 and zone 3, Borana, Guji, Karrayu, Bale, and Hararghe, south Omo and Nuer zones. A total of 2,106 households are included in this analysis.

Estimation strategy
Experimental and non experimental designs are widely used designs for impact assessments. However, the respondents in the large scale land investment are not randomly assigned. Therefore, a Propensity Score Matching (PSM) is used to avoid endogeneity (Bishop, 2015; Shete and Rutten, 2015). We classify households as being ‘treated’ if they are located (up to 150 km), otherwise. In addition a random effects model was estimated by including control variables. The dependent variable is food security measured by
using three indicators, food intake, self-report, and coping strategies index (CSI). In food intake, we use 1 for households that consumed at least 2,200 kcal/day/adult, 0 otherwise; in self-report 1 for households who reported being food secure, 0 otherwise; and in CSI, 1 for households with zero CSI, and 0 otherwise. Several control variables such as natural assets include the size of land owned, percentage of a forest, soil quality, and access to irrigation; human capital variables include age, gender, and education of the household head and household size; physical capital variables such as livestock and distance to road and markets; financial assets such as credit use and household income; social services such as access to extension, environmental shocks such as drought exposure, and livelihood strategy (if the household is a pure pastoralist or diversifying).

Results

**Propensity score matching results**

Overall, the share of food-insecure households in the agropastoral areas in our sample was 32%, Table 1 shows the food intake and self-report show an improvement of food security for 4.5% and 7% households, respectively. On average food intake increases by 744.71 kcal/day/adult for treated households.

<table>
<thead>
<tr>
<th>Table 1: Average Treatment Effects on the Treated (ATT) before and after matching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Kcal_AE_Day</td>
</tr>
<tr>
<td>ATT</td>
</tr>
<tr>
<td>Food intake</td>
</tr>
<tr>
<td>ATT</td>
</tr>
<tr>
<td>Self report</td>
</tr>
<tr>
<td>ATT</td>
</tr>
<tr>
<td>CSI (continuous)</td>
</tr>
<tr>
<td>ATT</td>
</tr>
<tr>
<td>CSI (dummy)</td>
</tr>
<tr>
<td>ATT</td>
</tr>
</tbody>
</table>

Source: Authors’ calculations based on LSMS data (2019)

**Random effects regression results**

The results in from the random effect regression show that proximity to an LSLI increases the probability of being food secure, and this result holds for the measures Food Intake, Self-report, and kcal per day. We also include interaction terms of the treatment variable with market and road distance and the net effect was 330.7 kcal/day/adult. The control variables that significantly increase households’ food security are land ownership, forest land, access to irrigation, and soil quality, household head’s education and gender, access to roads, and participation in extension services, whereas the factors which reduce the likelihood of households to become food secure are borrowing money (credit), age of household head, household size, and pursuing pure pastoralism. Livestock number and market distance does not have significant effect. Household income has a positive but small effect on food security in kilocalories per day.

**Conclusion**

About one third of the agropastoral communities in Ethiopia are suffering from food insecurity. The finding of this study shows that proximity to large scale land investments has no adverse implication on household food security measured by food intake and household self-report. This however does not mean that LSLIs have improved household food security as they actually denied them of access to pasture land. This is because of the relatively better pasture and water near to large scale land investments. The coping strategies index shows about 9% households become vulnerable to food shortage because of LSLIs (although the result is not statistically significant).

We suggest that policymakers release policies that guide large scale land investments to relate their investments to the livelihoods of the host communities, and ensure access to communal
rangelands for better food security. Further research could be done to explore the linkage between LSLI local employment and livestock productivity in an agropastoral context.

References


Exploring institutional complementarity and social thresholds of mobility in pastoral social-ecological systems in Mongolia

Kasymov, U.1; Ring, I.1

1Technische Universität Dresden, International Institute Zittau, Chair of Ecosystem Services

Key words: Tipping points; social thresholds; institutional change; pasture management; Mongolia

Abstract
Biodiversity continues to decline worldwide, affecting dryland ecosystems that are of significant importance for global biodiversity conservation. Accelerated by climate change, undergoing transformations have been pushing the entire social-ecological system across ecological and social thresholds. Particularly, the decline of pastoral mobility in Mongolia is of great concern, as flexible responses to the dynamic environment are crucial for the sustainability of drylands’ ecosystems. Responding to this concern, Mongolian policymakers design new pasture use and conservation policies. However, the policies might be ineffective in preventing systems from crossing the thresholds, unless policy implementation succeeds in systematically shaping the perceptions of a critical mass of herders and their strategic choices regarding pastoral mobility. We evaluate whether the enacted policies generate the intended consequences. First, we reconstruct the strategic choice and resulting institutions regarding pastoral mobility in the commons domain, where herders jointly use common pastures. Second, we track the process in the political economy domain, where pasture users choose to support or resist policies. Finally, we evaluate the complementarity of the strategic choices and institutions in both domains. In our field research, we employ the “process tracing” method. It relies on observations to trace recurring processes within and between herding communities and incorporates triangulation via various tools, such as expert interviews and focus group discussions. Our findings identify complementarity between the enacted policies and pastoral mobility as individual households comply with the rules and select mobile herding strategies. However, for the complementarity conditions to be held and to create an overall institutional arrangement, a critical mass of herders choosing to comply with the regulations and practice pastoral mobility to reach a social threshold will be crucial.

Introduction
Biodiversity loss significantly reduces nature’s capacity to contribute to people’s well-being. Current social-ecological transformations of drylands’ social-ecological systems (SES) push the entire ecosystem across ecological and social thresholds. Specifically, the decline of the mobility of pastoralists is of great concern, as flexible responses to the dynamic environment are crucial for the sustainability of drylands’ SES. In Mongolia, nomadic pastoralists’ sedentarisation changes their grazing practices, for example reducing mobility and use of grazing reserves. This change substantially impacts ecological and herders’ livelihood resilience (Fernández-Giménez et al., 2018). Temperate grasslands, including those of northern Eurasia, are among the most imperiled ecosystems on Earth. Eighty percent of Mongolia’s land area is rangeland, where interacting climate, land-use and changes in governance threaten the sustainability of Mongolia’s rangelands and pastoral culture. Particularly concerning are the potential ecological impacts of changing pastoral grazing practices—namely declining use of grazing reserves and pastoral mobility. However, like other grazing practices globally, there have been no empirical studies to evaluate the effects of specific Mongolian grazing practices on ecological function at a management scale. We collected data on the grazing practices of 130 pastoral households across four ecological zones and sampled ecological conditions in their winter pastures. We used a novel social-ecological analysis process to (1. As a result, more than 22% of rangeland have been heavily and entirely degraded (Densambuu et al., 2018). In a policy response, the Mongolian government is implementing new pasture use and conservation policies. These policies coordinate access to pastures and incorporate new pasture management approaches at the community level, including land tenure, community-based
management, assessment and monitoring of pastures, and resource use planning. The objective of this study is to evaluate whether the enacted policies generate the intended consequences. To do so, we investigate herders’ strategic choices in the commons and political economy domains and evaluate the complementarity of these choices and resulting institutions that coordinate pastoral mobility. We employ the equilibrium notion of institutions and define institutional complementarity when “one type of institution rather than another becomes viable in one domain when a fitting institution is present in another domain, and vice versa” (Aoki, 2001: 3005).

Materials and Methods

Study Area

In our study, we employ the “process tracing” method (Skarbek, 2020). It relies on causal process observations to trace recurring processes/events within a studied case by making “inferences about hypotheses on how that process took place and whether and how it generated the outcome of interest” (Bennet and Checkel, 2015 cited in Skarbek, 2020: 416). The method is recommended to study institutional change (Skarbek, 2020) and relies strongly on triangulation via various tools, such as interviews, focus groups, and participant observation. To investigate socio-ecological dynamics in the Mongolian steppe ecosystem, we include four provinces (aimag) in our study: the Tuv aimag in the central Mongolian region, as well as three eastern provinces – the Khentii, Dornod and Sukhbaatar aimags. Within these four provinces, ten core sites were selected for a more detailed analysis at the municipality (soum) and community (bag) level based on their differences between more densely populated and relatively pristine areas. During field research in July-September 2019, the research team travelled to all core sites and conducted 40 qualitative interviews with herders, administrators and experts. Furthermore, we conducted a focus group discussion at a stakeholder meeting on 28 August 2019 in Ulaanbaatar.

Results

Strategic choice and resulting institution in the commons domain

We follow the game-theoretic approach in our institutional analysis (Aoki 2001) and assume that herders represent strategic players who interact over repeated periods to use pastures and maximise their payoffs. It is costly for them to exclude others from using common pool resources such as pasture and water. The herders are interdependent as their payoffs depend on choices of other members of their community. The strategic choice is influenced by internal and external constraints, such as (i) knowledge about the consequences of herders’ action from the previous periods, (ii) a set of actions available to herders, and (iii) expectations of others’ strategic choices. The equilibrium of herders’ strategic choices creates institutions that coordinate pastoral mobility.

(i) Knowledge about the consequences of previous actions: Traditionally, Mongolian herders employed highly mobile and flexible herding strategies to effectively use the diverse heterogeneous resources of the grassland ecosystem (Fernández-Giménez, 1999). This valuable experience constrains their strategic choice today as well. A herder in our study area explains the reasons behind his choice of pastures: “Well, in spring, during the birth season, Gobi habitat is beneficial for milk production. However, if livestock grazes only in the Gobi habitat, it will be difficult for them to overcome the cold weather. Thus, we herd animals by switching between the Gobi and Steppe and letting them graze on different grasses”. Based on their experience, herders also use seasonal pastures allowing them to regenerate: “When the grass starts to grow well, we come here around the start of June until August. In August, we move to the autumn camp. […] When we move to the autumn camp, the area will regenerate” (a herder, core site 4). The herding experience instructs herders to respond to environmental uncertainties (e.g., created by the scarcity of pastures or decrease of their quality) by moving long distances to practice otor – rapid movements of a subgroup household with their livestock to a distant pasture. Often, herders are forced to move to other provinces and municipalities when overgrazing of their pastures occurs. Water scarcity or decrease in their quality, especially in summer, is another important factor that constrains the strategic choice as “herders follow the water”. The respondents noted that wealthy herders tend to move to remote pastures, but their choice is often constrained by water availability. Furthermore, natural disaster risks, such as extremely cold winters (dzuds), droughts and wildfires, increase environmental uncertainty and force herders to move.

(ii) Set of feasible actions: Income of Mongolian herders depends very much on livestock and livestock products. Cashmere wool and sheep meat are the most valuable products. These led to a substantial increase in livestock since 1990, mostly of goats (ca. 50%) and sheep (ca. 30%) (NSO, 2019). To maximise their benefits from using pastures, herders feasible set of actions is related to strategic decisions regarding livestock
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

abundance and pastoral mobility. To increase their herd, herders decide how many and what type of animals they keep (with a preference for sheep and goats). Herders balance their herd size and structure by selling weaker and older animals in autumn and keeping young and good-quality livestock. Herders tend to increase their herd size based on what a household can manage and feed on pastures available to them. Pasture users decide when and where to move to feed and drink their livestock using seasonal pastures. Some herders move for longer distances following growth of grasses: “Our winter pasture is far from here, it is about 30 km away. To get there, we need to move 3 to 4 times.”[…]. In the good old times, we moved 5 to 6 times.” (a herder, core site 3). However, many herders have significantly reduced their movement rising concerns by local authorities and experts. A soum governor in core site 7 complains: “Herders stay in one place for a whole year. Others switch between winter and spring camp, and during summertime going to the summer camp. As the distance between camps is not far from each other, herders just move around one place where pastureland degrades eventually.” The set of feasible actions related to pastoral mobility can be classified into two options: practising low to moderate pastoral mobility or moderate to high pastoral mobility.

(iii) Expectation of others’ strategic choices: Herders consider other pasture users’ choices to predict the consequences of their own choices. Competition and conflicts regarding access to pasture and water resources shape their movement decisions: “The main reason why herders do not want to move is their fear that others would take over their land for agricultural or mining purposes. […] Agricultural companies tend to use more areas than allocated to them” (a bag leader, core site 8).

Building on interviews from local leaders, experts and herders, we conclude that the equilibrium of strategic choices and resulting institutions in this domain is related to practising low to moderate pastoral mobility.

**Strategic choice and institutions in the political economy domain**

The herders’ strategic choice in this domain is to support or resist the policies. In the following, we briefly describe the Mongolian government’s policies and reconstruct the herders’ choices.

**Leasing and Certification of Land for Winter and Spring Camps:** Since 1998, the land for winter and spring camps can be leased and certified to individual herding households for periods of 15-60 years, allowing herders to control surrounding pasture areas (Fernández-Giménez & Batbuyan, 2004). The land-use rights provided by certificates are inheritable and can be extended for 40 years. Soum governors issue the land certificates to herding households after the land registration office recorded their applications at the aimag level. In our study area, the strategic choice is to support the certification policy. Especially, wealthy herders with high a number of livestock tend to legalise their land-use rights as they need secured places for their animals. For example, in core site 8, up to 50% of herding households have obtained the certificate. The share is higher in core sites 3 and 7 (up to 70% and 90% respectively). A herder from core site 3 explains: “We got the land certificate soon after we married and got our marriage certificate. We need the certificate because we always stay there during the spring and winter. These are winter and spring pastures of my parents, who have been here for a long time. […] Almost every herder in our community has his land certificate”. However, some communities (e.g., in core site 10) stop issuing certificates when land disputes occurred. In relation to pastoral mobility, the effect of broad support for policy certification is twofold. On the one hand, the land certificates secure access to pasture land excluding others (e.g., their neighbours, herders from other communities, mining and agricultural companies). Our respondents believe that by certifying winter pastures, conflicts would be resolved. On the other hand, the secured pastures through certificates encourage herders to invest in fencing pastureland and building winter shelters for their livestock. Consequently, such investments may also contribute to decreasing pastoral mobility: “When herders build shelters and fences for their livestock, they cannot move away for a longer period” (a bag leader, core site 5).

**Establishing Pasture User Groups (PUGs):** The groups are organised based on pasture units boundaries delineated together with soum leaders and herder representatives. They can also be based on already existing groupings (often kin-based) with delineated grazing territories. A PUG may consist of 10-50 households. Involved herders receive training, technical assistance and financial support (e.g., through access to micro-credits with low-interest rate). As of 2018, 830 groups were created in 11 aimags in Mongolia. In many cases, herder groups have signed rangeland use agreements with their soum governors (Densambuu et al., 2018). In our study area, several communities have been involved (e.g., in core sites 5, 6 and 7). The strategic choice herders face here is to support the policy by joining the formal group or to resist.
A bag leader explains the effect of the group membership: “We jointly organise the seasonal movements from spring to summer, autumn and then to winter camps. We discuss every month pasture use related issues. I think we do not have any unresolved issues regarding pastureland at the bag level. If we continue working like this for another year, there will be no problem in our bag at all” (a bag leader, core site 6). Also, the otor movement has been better organised: “During former times, only a few people used to move to otor. However, last year, 100% of people moved” (a herder, core site 6). Still, the majority of herdsmen has not yet been convinced. For instance, in core site 10, a soum governor complains that herdsmen are not very active and eager to form groups: “Herders believe that they are better off by caring for their livestock individually” (a soum governor, core site 10). Respondents informed us that many do not have enough information about the policy, but they do not rule out a possibility to join a group in the future. Local leaders recognise the need to support the creation of herder groups: “Herders are not moving to other places by themselves. They need to recognise their [collective] responsibility” (a bag leader, core site 7). It will take some time until a critical number of herdsmen would get on board. Until then, local leaders argue for patience: “Of course, no force. We should start with herdsmen who agree. If it is useful and productive, others will come by themselves. First, we need to raise awareness about the group activities, and then a majority of herdsmen may follow” (a bag leader, core site 5). Building on interviews from local leaders, we conclude that there seems to be a tendency that not enough herdsmen join PUGs to allow grasslands to recover after grazing periods.

Pasture Use Planning: By 2018, photo-monitoring of 4200 sites at seasonal pastures in 278 soums was conducted to provide annual information regarding plant cover in Mongolia (Densambuu et al., 2018). The collected data were analysed by Mongolian experts and included in the land management databases. The data helps in the estimation of the animal carrying capacity and animal stocking rates. Municipal administrations are responsible for creating annual pasture use plans, organising pasture movement that takes into account stocking rates and coordinating use of seasonal and emergency reserve pastures. Implementation of pasture use planning is vital for promoting pastoral mobility. However, the policy’s impact depends on how herdsmen respond to it with their strategic choices – to support the policy by following the pasture use plan or to resist.

Implementation of pasture use plans differs across the study area. In some communities, there was “no limitation on livestock and no directions to move” provided (a herder, core site 5). In others, the local authorities directed herdsmen to move to winter pastures with less snow and more vegetation (a herder, core site 10). The quality of pasture use plans differs significantly. It is more developed in soums where development agencies supported local experts in evaluating pastures and integrated pasture rotation in local resource use plans (e.g., in core sites 3, 4 and 7). Local leaders and experts acknowledge the challenge to convince herdsmen: “It is a long way until the majority of herdsmen will understand and follow. For instance, we persuaded a group of herdsmen residing in a particular area, to move to a different place from August to October, to enable pastures to recover. Meanwhile, livestock from another herder came to this pasture and ate grass there. The reason why people do not want to move is that they are afraid to lose their land to others” (a soum expert on land use, core site 3). At least for now, a majority of herdsmen in our study area did not follow pasture use plans and thus resist this policy.

Discussion and Conclusions
Herders face alternative strategic choices in the commons and political economy domains. Their strategic choices and institutions are complementary when benefits of herdsmen choosing to practice moderate to high pastoral mobility increase from choosing to support rather than to resist a policy, as well as when benefits of actors choosing support a policy increase from choosing to practice moderate to high pastoral mobility rather than low to moderate pastoral mobility. We could not establish a clear, stable institutional arrangement between the following strategic choices: practising moderate to high pastoral mobility and support the Leasing and Certification of Land for Winter and Spring Camps policy. Herders largely support this policy as it reduces institutional uncertainty by securing their access to winter and spring pastures, but it also encourages herdsmen to fence their winter and spring pastures and build winter shelters reducing their mobility. The study identifies institutional complementarity between the strategic choices to support Establishing PUGs and Pasture Use Planning policies and the choice to practice moderate to high pastoral mobility as some individual households joint groups, comply with the pasture use plans and increase their pastoral mobility. Both policy interventions are effectively reducing institutional uncertainty by improving knowledge about the consequences of previous actions, establishing platforms for negotiating pasture use and excluding external actors from
access to the resources. However, for the strategic complementarity conditions to be held and to create an overall institutional arrangement, a critical mass of herders choosing to comply with these policies, practising pastoral mobility, thus reaching the necessary social threshold will be crucial.

References


THEME 6. PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES

Topic: International Year of Rangelands and Pastoralists, Part 2 – Panel 3 and 4

Panel 3 Topic: Climate Change and Ecosystem Health
Action Plan for the International Year of Rangelands and Pastoralists (IYRP): The Case for Mexico

Huber-Sannwald, E.
Instituto Potosino de Investigación Científica y Tecnológica, A.C.

Key words: communal land, complex socio-ecological systems, co-generation of rangeland knowledge

Abstract
Drylands cover over 50% of the Mexican terrestrial land and these regions support a large rural population who depend on livestock production. The high spatial and temporal dynamics in the drylands constantly couple and decouple ecology, culture, economics, and policies, and thereby humans and land, i.e. pastoralists and rangelands. This presents great challenges for decision makers. Since the Mexican Revolution a large fraction of these rangelands has become communal (ejidos) whose members have the right to use the land for livestock production. These land reforms included important shifts in institutional arrangements and land governance structures favoring a large rural peasant population including pastoralists. In 1992, however, the amendments in Article 27 of the Mexican Constitution – driven by neoliberal policies - launched a wave of transformation in rural land tenure with strong impacts on the multifunctional pastoralist – rangeland landscape systems. The privatization of communal land had immediate biophysical consequences through the fragmentation and fencing of land: the building of earthen dams, high grazing intensity, land degradation, alteration of ecohydrological processes and landscape function, and the provision of rangeland ecosystem services for pastoralist communities and human well-being at large. By limiting access to land, social conflicts were triggered and pastoralist social structures disrupted, to the point of jeopardizing the future of the ejido as a local institution of governance. These changes triggered high levels of poverty and migration, an increasing degree of insecurity associated with illicit drug trafficking, together with inadequate land use policies in the light of climate change and socio-environmental contexts. Additionally, the competing interests in land use such as urbanization, mining, investment in renewable energy are major obstacles for pastoralists to be perceived as key stakeholders and decision makers to achieve sustainable production in rangeland landscapes. The current desire to strengthen communal efforts needs to focus on rangelands as social-ecological systems as well as areas which provide multiple biotic and cultural ecosystem goods and services. The demand for rangelands goods and services will eventually stimulate the generation and maintenance of highly diverse multifunctional landscapes. Fostering and incorporating local knowledge systems with participatory research will naturally lead to adaptive (to drought, price shocks, etc.) management and thereby enhance local food security, pastoral livelihood development, and rural sustainability.

Introduction
Mexican rangelands and pastoralists are highly diverse, interconnected socio-ecological systems spreading across a wide range of latitudes, altitudes, meso-climates, physiographic regions, soils, and ecoregions. The desert grasslands (US denomination) or semiarid grasslands (Mexican denomination) encompass the southern extension of the North American Grassland biome spreading from Canada through the United States to Mexico. These grasslands have evolved over millennia under nomadic grazing by large bison herds, recurring natural fires, and highly variable climatic conditions. With the introduction of domestic livestock during colonial times, large cattle herds (in tens of thousand) owned by large haciendas, gradually displaced the bison herds and expanded from the grasslands to the more abundant shrubland ecoregion. With this expansion of the rangeland types, livestock production got increasingly diversified (goats, horses, donkeys, mules, among others). The actual extension of rangelands in Mexico corresponds basically to the drylands covering 50% of the terrestrial surface. Marked social upheavals triggered by the Mexican Independence (1821)
and Mexican Revolution (1920) did not only transform the socio-political arena of this country but had strong transformative influences on the rural sector, a large peasant population and the dryland landscape.

With the introduction of land reforms and new land ownership legislation in the 1920’s, the communal land-tenure system (ejido) was created to provide usufruct rights to peasant communities (called ejidos) under the oversight of federal government and involving cumbersome bureaucratic pathways including the official registration process, through a National Agrarian Registry. However, in the wage of the emerging neoliberal economic capitalist model, the large peasant population locally organized in communal land tenure systems and the subsistence agricultural sector suffered increasingly from retraction of government support, which ultimately culminated in the 1992 legislative change in the Mexican Constitution (Art. 27) opening the communal/ ejidal land to privatization and sale. Over the next 100 years, these profound transformations in the socio-political structure of the Mexican agrarian sector, greatly impacted the Mexican rangeland socio-ecological system both as an institution and as a sustainable production system. The impacts mean that Mexican management, conservation and development practices are quite different to those in the rangelands of the United States of America and Canada. Hence, we consider it worthwhile to treat the Mexican rangeland region as a separate case study within the larger North American region.

**The contemporary rangeland/pastoralist landscape and perspective of Mexico**

Local rangeland socio-ecological systems have coevolved over many centuries representing diverse land tenure systems in different ecoregions. This process of coadaptation has shaped a great diversity of pastoralist livelihoods and generated profound local, environmental and indigenous knowledge on wild, semi-domesticated and domesticated animal husbandry, drought adaptation, animal breed functions, husbandry conditions, among others (Mora Ledesma 2016). Pastoralist communities are nomadic, semisedentary or sedentary depending on whether they raise livestock only or combine livestock production or wild animal care with rain-fed agriculture in case of agro-pastoralists. Local and regional animal breeds were originally selected for their functions, and only those that adapted best to the environment, husbandry conditions, and the demands of their holders survived. Commercial production of livestock has grown in response to expanding beef markets worldwide, in particular in the United States and Europe; this has drastically shifted the original vocation of supporting livelihoods in the rangelands in Mexico. While attractive from a local household economy perspective, high heterogeneity in rangeland production potential has contributed to a pronounced divides among livestock producers and rangeland condition. While private ranchers own vast productive semiarid and arid grassland (short-grass steppe or desert grasslands), communal rangelands expand in less productive ecoregions dominated by desert scrub and succulent shrublands. Hence, it has been the rancher class (ganaderos) that practices livestock production in the more productive semiarid grasslands that has been actively responding to trade opportunities such as the North American Free Trade Agreement without suffering land degradation. Ejido land, on the other hand has undergone greater pressure from people and livestock with pronounced declines in their potential to provide ecosystem goods and services and on their well-being (Martínez et al., 2020).

It is fundamentally important to maintain highly diverse rangeland ecoregions as life-support systems for a large rural population mostly depending on livestock production (65% cattle, 29% goats, 5% equines) to avoid urban and cross-border migration (Leighton Schwarz and Notini 1994). The current state and integral condition of Mexico’s native rangeland socio-ecological systems in the drylands regions, is poorly understood. The grassland biome of Mexico is a great exception, as national and international organizations and U.S. agencies have invested great efforts to protect and conserve the biodiversity of these ecosystems and promote their sustainable use (CEC 2015). In Mexico, 63% of natural grasslands are privately owned, 29% are communal land, and 7% is federally owned land (55 Natural Protected Areas) (CEC 2015). No comparable statistics are available for the Mexican shrublands, covering up to 70% of Mexican drylands, including UNESCO Biosphere Reserves, which are however the most abundant rangelands used by communal pastoralist communities, with little to no alternative income (besides occasionally remittances or ecotourism) (Martínez Tagüeña et al., 2020).

Land use pressure has mostly affected communal rangelands, human population growth and strong competing economic interests in development have promoted urbanization, mining, megaprojects such as greenhouses, windparks and solar panel infrastructure, fossil fuel extraction through fracking, among others. Increasing
of Mexican rangelands as sustainable life support systems for diverse pastoralist communities that strengthen human well being at large; as a reservoir of high genetic, taxonomic, endemic, biotic, functional, socio-cultural diversity linked to diverse complementary knowledge systems; by bridging and connecting among diverse groups and stakeholders, mental models, conceptual pitfalls and epistemological, ontological and teleological debates and narratives, disciplines, watersheds, policies, i.e. hard, soft and geographic and regional boundaries to the North and South.

Actions are proposed, given the current issues affecting rangelands and pastoralists, and gaps in knowledge and science, as summarised next.

**Issues affecting rangelands and pastoralists**

- Privatization of communal land and fragmentation of rangeland socio-ecological systems
- Lack of recognition and hence support of (nomadic) pastoralist identity, social organization and governance structures
- Land use change driven by megaprojects and interfering with transhumance pastoralist groups
- Climate change consequences including mega-droughts and flooding coupled with strong wind and water erosion
- Remoteness from central decision making and lack of access to basic services (health, education, communication, infrastructure, energy, water, food)
- Migration and loss of local generational pastoralist knowledge
- Lack of access to existing markets and of capacity to commercialize alternative rangeland products and services

**Knowledge & science gaps about pastoralism and rangelands**

- Understanding rangelands as complex socio-ecological systems and their multi-scaled nature
- Decipher (historic) land management signals from inherent landscape heterogeneity for the development of best management practices

The International Year of Rangelands and Pastoralists could and should help shape the future...
• Insufficient participatory research to collectively assess the socio-economic, cultural, and ecological values of rangelands to ranchers/pastoralists

• Lack of understanding of impact of adaptive management practices in diverse rangeland ecoregions, and on the how coupled the carbon and water cycle as proxy for climate change mitigation (not sure I have interpreted this correctly, it is a little confusing & I don’t think “coupledness” is not an English word)

• Lack of recognition of (changing) pastoral identity, and significance of mental models and traditional knowledge in ranching practices

• Lack of understanding of evolving impact of inappropriate government help programs, land tenure policies on rangeland condition, landscape – watershed function, restoration and communal (social) organization

• Lack of knowledge of high diversity of local traditional adaptive livestock production systems including locally adapted breeds

• Lack of attention to local needs and interests of ranchers/pastoralists in diverse rangeland landscapes

• Lack of research on the synergistic role of pastoralism in achieving sustainable development goals

• Develop participatory rangeland monitoring-assessments protocols with pastoralists and user-friendly field-based data collection technology as a hands-on tool to understand and manage variability

• Assess the impact of privatization of ejidos on pastoralist household economies, social organization and rangeland functioning

• Promote awareness-raising of high diversity of traditional rangeland-pastoralists systems through IYRP

• Co-generate a participatory research agenda to promote pastoralist partnerships to contribute achieving the sustainable development goals (climate action; equity: gender, economy; food security; rangeland conservation; among others)

• Co-assess potential pathways for a new rangeland/pastoralist narrative from resilience to transformation as an adaptation to climate change

• Propagate rangeland biosphere reserves and natural parks as socio-ecological flagships for biodiversity conservation

• Develop a dynamic map of rangeland biodiversity hotspots

• Generate and support virtual and in situ pastoralist-to-pastoralist exchange programs to foster cross-fertilization of farming experiences under changing climates, between the North American and Latin American region and cultures

• Support young pastoralists in diversifying their livelihoods linked to complex socio-ecological production systems

• Encourage and establish local governance institutions that are nationally acknowledged and supported

• Identify all socio-political and economic cross-scale interactions that influence and control local rangeland/pastoral systems

Actions proposed to acknowledge and foster stewardship roles of pastoralists to sustainably manage diverse rangelands

• Promote transdisciplinary partnerships (academia, pastoralists, public sector) that advocate and support low income/subsistence seminomadic ranchers/pastoralists and their role as rangeland stewards

• Lobby for rancher-science-policy nexus to foster policies for sustainable development grounded on complex socio-ecological systems understanding

• Acknowledgements

We thank the International Network for Dryland Sustainability (RISZA) and PRONATURA
Noreste for supporting the initiative of the International Year of Rangelands and Pastoralists.

References


Challenges of pastoralism and rangelands in Europe

Manzano, P. 1,2.

1Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland; 2Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland

Key words: Europe, intensification, rural depopulation, ecosystem services

Abstract
High Human Development achievements across Europe explain the situation of pastoralism in the region. While its economic importance has dwindled over the last century in terms of livelihood provision, pastoralism is nonetheless key for supporting rural population - especially in the areas of lower agricultural potential - and for delivering ecosystem services in vast areas. The mainstreaming of scientific research means that pastoralism is increasingly recognized as a sustainable livelihood by the European general public. In spite of this better press, the advanced average age of European pastoralists and the increased gender imbalances pose great sustainability risks in the short- to medium-term. Some pastoralism-shaped ecosystems such as the Southern Finland pastures have already collapsed. Negative climate change narratives around pastoralism are triggering climate action plans that threaten extensive, highly biodiverse pastoralism landscapes in various countries, such as the British highlands. The process of agricultural intensification and rural abandonment in Europe poses other threats, such as poor service delivery and increasing human-wildlife conflicts, notably with disease-carrying forest species such as the wild boar or some predators that are experiencing a comeback.

For pastoralism to survive in Europe, the holistic role of pastoralism in ecosystem conservation as a whole should be recognized. This includes changes in the Common Agricultural Policy, especially at the national level of implementation (also eco-schemes, rural development interventions), to incorporate payments for ecosystem services that eliminate the competitive disadvantage with more intensive production systems. Encouraging urban, young people to become pastoralists, as well as promoting preventive measures for human-wildlife-conflict, rather than compensatory ones, are also urgent and necessary steps.

Knowledge gaps still persist that hinder effective policy and advocacy action. Better understanding will come from effective collection of national and continental statistics related specifically to rangelands and pastoralists; improved integration of traditional ecological knowledge into policy and land management at a continental scale; and building on the history of how pastoralism has shaped and maintained European natural landscapes. Landscapes in Europe are not as dominated by forests as the general public and most of academia usually believe.

Historical introduction
The European history is greatly influenced by pastoralism. It started in the southern Balkans in the late seventh millennium BC (Ethier et al., 2017) and extending northwards and westwards from there, reaching the Atlantic coast of the Iberian Peninsula less than thousand years later (Tejedor-Rodríguez et al., 2021). Much the cultural diversity in the continent is related to pastoralists, beginning with the origin of the dominant Indo-European languages in the Central Asian yamnaya nomadic culture (Olalde et al., 2018, 2019). European biodiversity and seminatural landscapes are maintained largely by the herbivory of domestic livestock, which inherits its functionality from now extinct megafauna (Vera 2000).

The last century, however, has witnessed great changes in European rural areas that have affected both the landscape and its inhabitants,
coupled with the strong economic development of European countries. Regarding landscapes, the areas with highest agricultural potential have seen a rash urbanization and an intensification of the agricultural production, creating industrialized livestock production systems with high grain inputs and weak links to the land. Meanwhile, many lands of marginal agricultural production that are naturally used by pastoralists have been depopulated or even completely abandoned, leaving space for tree plantations, secondary forests, scrubland (Stoate et al., 2009), or wildfires (Damianidis et al., 2020). Such abandoned landscapes have allowed for the increase in numbers of wildlife such as wild boars (Frei et al., 2020, Valente et al., 2020) or wolves (Chapron et al., 2014), which are welcomed with joy by overwhelmingly urban, land-sparing and animal-welfare oriented (Manfredo et al., 2020). Women and youth have massively left rural societies, challenging their social sustainability in the long term due to lack of generational replacement (Manzano et al., 2021). In addition, climate change narratives have put pastoralism in the spotlight, being accused of large-scale Greenhouse Gas Emissions both through methane emission by enteric fermentation (Manzano & White 2019) and of soil carbon release through the transformation of forests into pastureland (Hayek et al., 2021). As a result, the predominant vision on European pastoralism during the 20th century was of a back-laid, inefficient, primitive livelihood that should be abandoned.

**Developments in the last decades**

The last decades have seen a change of paradigm in Europe. Pastoralism values are associated with land-sharing conservation (Fischer et al., 2014) and its loss is linked with the disappearance of species that depend on sunny, open habitats, with increased number of wildfires in Mediterranean Europe, and with rural cultural loss mediated by depopulation. Former alliances are thus weakening, including the agricultural unions that host both industrial and pastoralist livestock keepers, or environmentalist organizations that host both animal rights activists and ‘land-sparing’ conservation advocates, and conservationists leaning partially or totally towards a ‘land-sharing’ approach. New alliances are being forged among former foes: pastoralist livestock keepers and conservationists with an ecosystem perspective. An increased interest in high-quality foods that express local cultural specificities has also facilitated positive policies (Charbonnier 2012). All these factors have improved the economic status of pastoralist livestock production systems in the continent. Such changing perceptions and alliances have highlighted the value of pastoralism for much of the wider public as a way of ‘retro-innovation’ to tackle some of humanity’s greatest challenges. Some initiatives include the establishment of herding schools to encourage young urban population to adopt pastoralist livelihoods as a life choice. Despite the improvement in the environmental and economic aspects, the question arises on whether the social erosion that European pastoralism has been subjected has been too severe, and whether positive tendencies are arriving too late. In e.g., Southern Finland, seminatural grasslands are the only ecosystem in the country classified as ‘critically endangered’ by IUCN’s Red List of Ecosystems (Kontula & Raunio 2018).

**Future undertakings**

**Priority actions:** In light of the current situation, pastoralist advocates require a series of priority actions to raise awareness to policy makers. **First,** current understanding of the fundamental ecosystem process supported by pastoralism, justifies a public investment into the maintenance of its roles, through payment of ecosystem services. Services from mobile pastoralism include the maintenance of: complex open landscapes, with a mixture of trees, shrubs and pasture (Perea et al., 2016); the maintenance of wild pollinators, whose crisis threatens European commercial crop agriculture (Hevia et al., 2016); the maintenance of seed dispersal and pollination that avoid plant inbreeding in a dangerous climate change context (García-Fernández et al., 2019); or the recruitment of trees in parkland landscapes (Carmona et al., 2013). **Second,** is the promotion of urban youth into pastoralism practice. Improved access to education in Europe has increased the array of professions available to young people and facilitated mobility across professions – e.g., the child of a bank worker is unlikely to work in a bank and is likely to choose a different professional specialization. However, European agrarian policies so far are focused on keeping recruiting new professional pastoralists exclusively from established pastoralist families. This ignores the generalized opportunities to opt out of pastoralism brought by widespread education in Europe. But this also ignores the opportunity for urban youth who wish to work close to nature while living under adequate live conditions. Such an understanding and change in policies will contribute to the generational sustainability of pastoralism. This requires adequate capacity building through pastoralist field schools, and also an adequate rural entrepreneurship environment with through a fair access to Common Agricultural Policy (CAP) rights, conditions that are currently insufficiently met for newcomers. **Third,** is the growing number of wildlife causing Human-
Wildlife Conflict (HWC). Wild boars or wolves are a great source of unfairness. Advocacy for the preservation of such species is overwhelmingly urban, but their presence and, especially, induced costs, is imposed to rural inhabitants, often in areas with marginal agricultural productivity. Policies are urgently required to minimize HWC by systematically implementing effective preventive measures – valuing traditional systems, and not just providing compensatory payment. This reduces the often-ignored emotional burden of HWC to these rural populations both in terms of losing beloved domestic animals that their livelihood depends on, and of having the burden of proving HWC’s damages.

Research gaps: Pastoralism advocacy in Europe also suffers from knowledge gaps that hinder it reaching its full potential. These include: (i) Knowing the number of European pastoralists. No national statistical services collect separate data on livestock keepers according to their degree of extensification. Criteria are not clear on how to define the variable “extensification”, even if the CAP does include specific payments to reward it. Ignoring the number of pastoralists poses challenges in terms of the services they need or in knowing their economic, social, and ecological significance. A clear, continental-wide definition of pastoralism needs also to be agreed among scholars working on pastoralism in Europe. (ii) An inventory of the ecosystem services provided by pastoralists. The extent of ecosystem services from pastoralism (Manzano-Baena & Salguero-Herrera 2018) is impossible to estimate with accurate statistics on their numbers and the land they use. In addition, the information of the services themselves is partial, concentrated in the areas that have been surveyed by pioneering scientific teams. Maps are missing on the distribution of ecosystem services, and where knowledge gaps should be covered. (iii) Outcomes of forestation policies. The widespread perception of forests as the climax vegetation in Europe has promoted forestation in the continent for multiple purposes (restoration of biodiversity, carbon fixation). But the outcomes have not been evaluated and are challenged by vegetation ecologists (Pausas & Bond 2019). Such policies have targeted grazing ecosystems that are also in danger in other parts of the planet (Bond 2016). By grasping such losses and its outcomes, including not only biodiversity loss (Kontula & Raunio 2018) but also negative climatic effects in terms of a lower albedo (Bonfils et al., 2012, de Wit et al., 2014), a better understanding of forestations done at the detriment of pastoralist areas will help advocating for more reasonable land use policies. (iv) Systematization of Traditional Knowledge. The huge heritage of pastoralist traditional knowledge has been partially lost through rural emigration, is poorly documented and is also difficult to add into databases, as much of it is only available in local languages. It is often poorly understood, and adaptive changes in the knowledge of newer generations are easily mistaken by cultural erosion. Traditional knowledge needs to be better understood and systematized (Sharifian et al., 2021).

Knowledge gaps among the general public
Some knowledge gaps affect the general public in spite of having scientific evidence. These include: (i) The acceptance of the value of pastoralist products. Pastoralist products have a higher cost of production and are therefore less competitive than other livestock products issued from industrial production. Their distinct advantages need to be valued e.g., better nutritional profiles, higher animal welfare, ecosystem services associated to their production, or territorial/cultural values associated with their character of local products (Manzano-Baena & Salguero-Herrera 2018). The existing market for these products could be greatly enlarged if such distinct advantages were much better known among the general public, who often knows none, or only one of many. (ii) Potential extent of wooded pastures and parklands in Europe. European environmental education and culture is still tightly bound with trees and closed forest (Vera 2000), ignoring the open character of European landscapes which have existed since the end of the Miocene 12 million years ago (Bond 2019). Valuable pastures are still forested among ‘ecological restoration activities’, and even large-scale forestation projects such as the UK Climate Strategy target biodiverse pastures. A better dissemination of state-of-the-art knowledge on vegetation science is urgently needed to better inform the general public on these issues.

Conclusions and implications
The progress of bridging research gaps has occurred to some extent. One example is the rescue of wooded pastures, which are very significant in many European pastoralist systems (Plieninger et al., 2015) and a fundamental part of the 3-layered natural landscape structure. A continental-wide call for a CAP reform considers wooded pastures in a fair way (EFNCP 2016). Secondly, a greener and socially fairer CAP is called for by academia (Navarro & López-Bao 2018, Pe’er et al., 2020), and echoed by a wide array of European civil society organizations. While the results of the current CAP attempt are limited or deceptive (EEB 2020), elements of reform or of other parts of the EU Green Architecture that include...
environmental (Röder & Matthews 2021) or social (Matthews 2021) aspects show that joint lobbying is worth the effort. The proposed International Year of Rangelands and Pastoralists in 2026, fuelled by the participation of some European pastoralist organizations and many Europe-based pastoralism experts, should also add momentum for a favourable reform of pastoralism-related policies in the continent.

In summary, pastoralism has a lot of challenges in Europe that require a lot of effort to be worked out. Still, the developed nature of European economies and the recognition that pastoralism has achieved in the continent in comparison with other areas invite to optimism. Pastoralism advocacy is well placed to build on top of past efforts and make Europe a model for fitting pastoralism in modern societies worldwide.

Acknowledgements
This research was funded through HELSUS and the International Union of Biological Sciences (IUBS).

References


THEME 7. CAPACITY, INSTITUTION AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS

Topic: Participatory Monitoring and Silvopastoral Systems
Silvopastoral strategy and sustainable management of forests in Morocco

Mustapha, N; Said, L; Said, M and Anass, L.

1Engineer forestry - Water and Forestry Department, Morocco
2National School of forest Engineer, Morocco
3Mohammed-V University, Faculty of Science, Morocco
4Engineer forestry - Water and Forestry Department, Morocco

Abstract
In Morocco, forests act as a grazing reserve all year long and in a normal year produce 1.5 billion feed units, i.e. 17% of the national forage assessment. The pastoral question is one of the factors involved in the desertification of forested areas against a bioclimatic background where more than 93% of the national territory is arid. In 2016, the Water and Forestry Department in cooperation with its partners, devised a nation-wide silvo-pastoral strategy. The approach adopted consists in sustainably managing silvo-pastoral resources over the long term based on good governance of all goods and services offered by forested areas. This silvo-pastoral strategy deals with questions relating to the restoration of natural ecosystems, governance and access to resources, the revival of pastoral practices and capacity-building at the local level.

Key Words: Forestry, silvo-pastoral strategy, Morocco

Introduction
Morocco has a very rich plant and animal heritage thanks to the great diversity that characterizes pastoral and silvopastoral ecosystems. In addition to their potential in terms of breeding, the so-called pastoral and silvopastoral zones conceal wealth which can help the populations diversify their income. The silvopastoral sector benefits from the existence of a legal arsenal and regulatory framework which is constantly evolving, but also from a set of appreciable experiences in the management of development projects in the forestry field through policies and programs aimed at pastoral improvement within the framework of integrated development projects.

A national consensus on the problems and constraints to the development of the silvopastoral sector is reflected by the actions of the Department of Water and Forests, which has always maintained collaborative and concerted relations with its partners in the development of pastoral breeding, in particular the Ministry of Agriculture, Maritime Fisheries, the Ministry of the Interior and user population organizations.

Issue
Given the scale of population growth in forest areas, the sedentarization of pastoralists, the growth of the market economy and the recurrence of droughts, the modes and practices of using forest resources have undergone profound changes leading to major imbalances between pastoral supply and demand in forest areas.

The main elements of this issue are summarized as follows:

- Irregular and threatened silvopastoral resources;
- A fodder deficit linked to excessive withdrawals of pastoral resources;
- Conflicts of use in silvopastoral areas amplifying the degradation of resources;
- Poor knowledge of silvopastoral systems and insufficient valuation of experiences;
- A multi-actor issue (multidimensional) and a lack of a common vision.

To be able to deal with these issues, this research work started from the following question: which approach to consider to build a sustainable silvopastoral strategy.
Methodology and strategy development process

The development of the silvopastoral strategy in Morocco required the use of a highly participatory approach. Indeed, stakeholders, partners and several stakeholders in the sector were involved on its design and mode of implementation, either through interviews, workshops, meetings or committee. The work approach was carried out in several phases described as follows:

- Development of a precise silvopastoral diagnosis in order to better explain the related issues;
- Capacity building in strategic planning to ensure a solid anchoring within the humane resources of the Department of Water and Forests;
- Organization of interactive workshops for strategy formulation;
- Forwarding workshop results to strategic managers for a uniform understanding of the orientations of the new strategy;
- Formulation of the strategy in a simplified, well-structured language ensuring visibility and readability of its content;
- Restitution of the new strategy to institutional partners and to civil society.

Main axes of the strategy

The main strategic axes are presented below:

First Strategic Axis. Reconstruction of ecosystems as silvo-pastoral resources

This involves supporting restoration programs aimed at improving the forage supply in the forest and limiting pastoral pressure on forest stands. The main activities retained consist of: (i) strengthening silvo-pastoral improvement programs by giving priority to fodder shrubs and native perennial species which makes it possible to provide fodder reserves that can be mobilized in times of drought, (ii) initiation and popularization of good pastoral practices, (iii) the development of management plans and concerted exploitation of silvopastoral improvement perimeters.

2nd Strategic Axis. Improvement of the organization of users of silvopastoral resources

The success of measures and practices for the rational management of silvo-pastoral ecosystems remains conditional on the organization of users in associations or cooperatives. The main activities consist of: (i) the mapping of the beneficiaries of the users of silvopastoral spaces, (ii) the support and accompaniment of the creation of local user organizations in associations or pastoral cooperatives, (iii) the rehabilitation of good management practices of silvo-pastoral resources, (iv) contractualization of commitments with pastoral organizations for the exploitation of silvopastoral resources by territorial units.

3rd Strategic Axis. Support for the socio-economic development of forest areas

The main activities retained relate to: (i) improving the management of livestock systems, (ii) enhancing the value of livestock sectors (wool, goat cheese, etc.), (iii) developing generating activities income through the identification of the main wood and non-wood forest products to be developed, and (iv) the strengthening of users’ skills in terms of sustainable development of the products.

4th Strategic Axis. Improving the governance of silvo-pastoral resources

This is to improve the operational coordination of actors so that it is more effective and aligned with the needs of sustainable management of silvo-pastoral resources. The main activities retained consist of: (i) the development of a common vision between the various actors concerned, (ii) the generalization of pastoral and silvo-pastoral development plans by integrating the concerns of the various institutional actors and by specifying their commitments and their contribution to the implementation of the said master plans.

5th Strategic Axis. Holistic and dynamic research and development

This is to strengthen research and development enabling it to collect, analyze and disseminate the information necessary for sustainable management. The main activities consist of: (i) the constitution of repositories of sustainable agro-silvo-pastoral systems, adapted and applicable to the various pastoral species, (ii) the appropriation of the research results available from the various actors, (iii) the creation of interactive databases between researchers and managers, and (iv) developing socio-economic management models specific to the different silvo-pastoral areas.

Conclusion

The silvopastoral issues needs to be approached from the perspective of rural development and following a participatory approach for sustainable development. The efforts made for the development of the silvopastoral sector deserve
to be consolidated, strengthened and improved through institutional and partnership mechanisms and tools likely to promote synergies between the various stakeholders.

The construction of this national silvopastoral strategy integrated the visions of the various institutional partners. Such integration can only be effective within a unifying framework within which each stakeholder will act according to its missions, resources and responsibilities by converging towards a single and harmonized objective.

In order to combine the interventions of the various institutional partners as well as civil society and community and pastoral organizations, the silvo-pastoral strategy constitutes an adequate framework for bringing together said partners in a logic of complementarity and in a manner adapted to each silvopastoral context.

References

Administration des Eaux et Forêts et de la Conservation des sols (DEFCS), (1999). Rapport de synthèse du Programme Forestier National du Maroc. 120 P.


Status, management, and governance of the communal grasslands of Ethiopia’s highlands: a disappearing asset for mixed crop-livestock livelihood systems

Bedasa, E.1; Fiona, F.1; Tesfa, G.2 and Jason, S.1

1International Livestock Research Institute (ILRI),
2Debre Birhan Agriculture Research Centre, Ethiopia

Key words: Ethiopia, highlands, communal grassland, governance, management, restoration

Abstract
There is little documentation about the status, management, and governance of the communal grasslands of Ethiopia’s highlands. However, research being carried out by ILRI (International Livestock Research Institute) in northern Shewa, Amhara region, is highlighting their importance as a critical resource for those farmers engaged in mixed crop-livestock livelihood systems across the highland areas. These grassland areas range from 2 to 200 hectares and can be used by up to four different villages or ‘kebele’ and providing on average 10-20% of livestock feed for local farmers. However, this important resource is rapidly disappearing with encroachment of farming and tree-planting with species such as Eucalyptus spp. that kill grasses. The remaining grassland is often degraded through poorly organized grazing and overuse. In the past these communal areas made up around 50% of village areas, but this has now significantly reduced. Most of these communal grasslands have effectively no management and governance system, and rather are open access for all the local population with livestock to use. This situation results in almost no resting of pastures from grazing. Unlike individual lands in the area, landholding certificates are not provided for these highland communal grazing lands. Though in other parts of the country including in Amhara region, some of these lands have been registered to community user groups, this is not the case in most of northern Shewa. These findings show the need to improve the management/governance of these important communal resources with available opportunities through engagement and participation of the communities and stakeholders. Finally monitoring systems would be useful to detect changes in the communal grasslands condition, whether management adjustments should be made, and to provide recommendations for communities throughout the highlands on practical and effective grazing management strategies.

Introduction
The constitution of Ethiopia validated, and confirmed state ownership of land and farmers only receive usufruct rights to plots of land without transfer rights and unclear tenure security (Crewett et al., 2008), and this resulted in exacerbated the problem of land degradation with coupled the subsistence nature of farming (Gebremedhin and Nega, 2005; Gebreselassie, 2005). There is an attempt of providing systems of land registration through certification, may be one route to providing such assurances, but the process of certificate issuance is not completed in most areas (Gebreselassie, 2006) and, for example, from 21 communal grasslands, only two have legal certificate for the users (Eba and Sircely, 2020).

The grasslands of Ethiopia are found in Afro-montane and Afro-alpine grasslands regions, which covers around 490,000 km² (Mengistu and Mengistu, 2015). Several types of grasslands provide livestock grazing in the highlands of Ethiopia. These include privately owned grazing areas, and communal grazing areas such as riverside and lakeshore grazing areas, roadside grazing areas and in some cases dry season grazing reserves (Zewdu 2005). Communal grazing lands have been important sources of livestock forage (Haileselassie et al., 2012) and are integral to the maintenance of the environment, requiring efficient use and conservation of grasslands. However, it is one of the most threatened land use types, mainly due to conversion of land to other land uses, like cropland and plantation of trees (Tesfay 2010; Yadessa 2015; Tesfay et al, 2016), and hence unregulated use and heavy grazing causes degradation (Gebremedhin et al., 2002). The underlying causes of land degradation include incomplete property right systems that may create
a perception of tenure insecurity. In the mixed crop-livestock production system, production of both crops and livestock will benefit from efficient utilization of grasslands and small plots of land. In the higher altitude zones, despite enduring efforts, intensive crop production has been constrained by frost and poor soil fertility (Gebre 2009). This has shaped the degree of dependency on livestock as well as crop enterprises. In the study area, farmers are limited to barley production and sheep farming. In Menz Gera woreda about 90% of the feed for the sheep comes from grazing lands (Haileselassie et al., 2012). Despite the importance of communal grazing lands, a comprehensive assessment of current communal grassland status, management, and governance, how these vary among communities, and their implications for effective investments are generally lacking. In discussions on these grasslands, attention is more often focused on how to covert the grasslands to other uses rather than on their important role in the integrated crop-livestock system (Mekoya et al., 2009). As such there is a need for better understanding these grasslands, their status and changes taking place. With this improved understanding it is anticipated that the protection will be better appreciated. In the presence of communal action, institutional and organizational development, positive impact on communal resources is more likely to be realized. The success of public policies to improve natural resource management depends to a large extent on the presence and effectiveness of local level institutions and organizations (Jabbar et al., 2000). And devolving rights to local communities to manage resources, establish use rules and regulations, and enforce the rules is a necessary condition for successful community resource management.

Materials and Methods

Study area description

In response to the above, this study aimed to assess the communal grasslands resources in the Menz area of Ethiopia, together with their importance, management, governance and access. More specifically, the study was conducted in Menz Gera and Menz Mama woreda of North Shewa Zone of Amhara Region, in the Central Highlands of the country (1,669–3,563 metres above sea level). In this area agriculture is characterized mainly by mixed crop-livestock production systems (Gebre 2009). The mean temperature ranges from 6.7°C to 17°C and mean annual rainfall is 896 mm. Sheep is the major component of livestock herd composition in Menz Gera and Menz Mama.

Method of data collection

Data were collected from a combination of field observation, biophysical data collection, focus group discussion (FGD) with farmers (8-11 from different member of communities), key informant interviews (KII) with kebele and woreda leaders, and secondary data from woreda and zonal Agricultural Offices. Ranking of livelihood strategy and feed sources in terms of importance were also used. Eleven communal grasslands from the two woredas were selected for the study with the involvement of woreda and their respective kebele agriculture experts. Among the communal grasslands selected, four were selected for quantitative spatial grassland monitoring. In each of the four communal grassland six sampling points using LandPKS (Riginos et al., 2011) were established. The Land-Potential Knowledge System (LandPKS; landpotential.org) is a new, innovative technology that collects spatial data about soils and vegetation with mobile phones to strengthen and enhance sustainable land-use planning, and support sustainable land management (Quandt et al., 2018). Data were collected in November 2019, after the rainy season. Descriptive analysis of FGD and KII data were used to identify the nature and status of community management on grazing lands, the role of local and external organizations, the institutions that evolved to manage communal grasslands, and their management and enforcement mechanisms.

Results

Status of communal grassland and is importance

Communal grazing areas were very common in Menz, but now shrinking in many areas. The grasslands are grazed by all livestock species (cattle, sheep, goat, and equines) throughout the year without any rest though the intensity of grazing differs. This may result in the depletion of palatable species, and in some areas results in invasion by less palatable weedy and shrubby species. The estimated area of the communal grasslands ranges from 2 ha to 200 ha, with the number of households using each grassland between 15 and 800. The number of users of the grassland have increased over time as population has grown. The communal grassland contributes to average around 13% of annual feed sources of the livestock (ranging from 10-20%) and placed 3rd among feed sources. In four communal grasslands the respondents prioritize livestock first as their main livelihood strategy. In areas where people perceive livestock as more important, especially sheep are used as ‘cash’ because they can be sold to meet urgent monetary needs. Other uses include
stone extraction, collection of dung and in a few communal grasslands there is wood collection for fuel, water sources, and collection of plants. Today these communal grassland resources tend to be open access with no management or plan for use. No restoration interventions have been undertaken on most communal grasslands, but gradual conversion to other land uses such as for crop cultivation or woody plantation is common. Most communal grasslands were used for varied purposes, such as for grazing, stone extraction, collection of dung and, in few communal grasslands, wood collection for fuel, household water sources, and spices such as thyme (Thymus vulgaris). Some of these resources are especially important for local livelihoods, such as stones for house construction (usually dug from unproductive areas) and clay for making pottery. A few communal grasslands had salt licks and were sources of grasses for thatching and making household equipment. All community members including women and youth used these resources. In areas where the communal grasslands were large and used by people in multiple villages, their resources were shared with neighbors including those that were not members of the community. But where the area of communal grassland was small it was used by the residents only. In some communal grasslands, especially the small ones, the users have the responsibility of protecting them from outsiders especially to make sure outsiders do not graze their animals on them when the pasture is not in a good condition. The situation was, however, different during dry seasons, when access was not restricted, even for outsiders. Access tends to be more restricted during the rainy season when the farmland tends to be covered with crops and the private grazing land is protected from livestock: at this time, the livestock keepers use their respective communal grasslands to support their livestock. In a few communal grasslands, users are responsible for protecting the areas from encroachment—by ensuring that trees are not planted, and by preventing privatization and expansion of cultivation and settlements within the grassland. One woreda expert said that ‘near one communal grassland, there was a communal grassland developed for [integrated] watershed [management]. In this watershed, trees like eucalyptus were planted that through time suppress the herbaceous vegetation.’ Such a case calls into question how the feed base is considered when planting browse trees as a way of improving communal grasslands, because all trees will compete with grass if their growth is uncontrolled. In another site the respondents were wary of getting involved in this study as they were highly suspicious of any discussion on the issue of the communal grasslands following a past attempted intervention by the woreda forest enterprise trying to convert the communal grasslands to a tree plantation, which had started as a similar conversation. The size of most communal grasslands has decreased over time due to the conversion of some of the land for cultivation and tree planting as described above. This has increased grazing pressures on other areas. Access to the grasslands is not negotiated individually but rather it is open for all to use with informal ‘rules’ often just ‘known.’ Community members are consulted by the government when land is needed for giving to the youth for crop farming for example, and generally they agree to this change of use, as the youth need land. Youth who do not have access to cropland may use the communal grasslands for livestock breeding and fattening. Different user groups tend to have the same access to the areas, with no advantages or disadvantages experienced by women and youth. The respondents indicated that the livestock productivity, such as milk yield had decreased. The respondents indicated that around all communal grasslands, the current livestock number was not balanced with the available communal grassland for grazing throughout the year.

**Management and governance of communal grassland**

According to the clear majority of respondents, there was no established management or governance body that was responsible for managing access and use of the communal grassland areas in this study. In one communal grassland, there was a traditional association known as ‘edir’ at the village level, which plays some role in management. Traditionally, this association helps members in covering costs of different social events (e.g. funerals and weddings), but in this village the community also use the edir for communal grassland management. However, in general there was no management planning for the areas themselves. In some cases, the areas fall under broader watershed management programs. Especially in Menz Mama woreda, most of the communal grasslands there fell under watershed management programs and this had resulted in significant tree planting in these areas. In Menz Mama, the community using the grazing land studied had a certificate of user right for the communal grassland that had been issued by the woreda administration. The data from Menz Mama woreda also shows that 340 communal grasslands that cover of 1659.6ha were given certificates. The kebele and woreda land administration heads signed on the ownership certificate. All households head that have access to communal grassland were included on the
user right certificate. This communal grassland not shared to outsiders specially during rainy season, where this season is the critical feed shortage. All household members (men, women, and youth) who have got user right certificate in common have access to resources of communal grassland. However, in Menz Gera woreda, all but one of the communal grasslands assessed had no certificate of user right for communal grasslands, and in nineteen kebeles of Menz woreda there are about 153 communal grasslands that encompass about 5749.31 ha. For these communal grasslands there were no clear data of woreda that reveals the certificate ownership given to them. The data from focus group discussions shows that only around 10% of the communal grassland studied have certificate of ownership. For the one of the communal grasslands in Menz Gera, the community had a certificate of ownership from the kebele administration with names of two representatives out of a total of 42 users of the grazing land that represent their household. These rights included anyone who marries among the users. Certification process was initiated through discussions among the users who then put the request to the kebele administration. The respondents indicated that when the watershed management was implemented on the communal grassland most of the users of the communal grassland did not agree and resisted implementation. This disagreement resulted in users asking for certificate. The respondents indicated that once the community received a certificate, users gained a sense of ‘ownership’ and could now start improvement programs, like terracing because they gained confidence that the land would not be put to other uses (e.g. crop cultivation), showing a clear improvement in perception of tenure security over the communal grassland. In general, data from North Shewa zone of rural land administration indicated that communal grazing lands which have certificate was 76% (17,864 ha with 10436 users (male 8644 and female 1792)), but in some woredas like Menz Gera the available certificate was very few. This is because of lack of initiative and responsible users to process for getting certificates. Though the users here are known their security of access is poor as they have no proof of right of use. In all the communal grasslands there are no rules or bylaws controlling use, access, control, and improvements of the communal grasslands. All the respondents indicated that the grassland will only be improved if the government gives support through such as cash-for-work. The communities did not feel capable of organizing themselves but require assistance for improving management, controlling unwanted weed plants, creating proper use plans and management plan etc. So far, almost no interventions have been done to improve the productivity and quality of the pasture in the studied communal grasslands.

Vegetation status of communal grassland

The respondents indicated that the vegetation regeneration ability, availability, and quality on communal grassland has decreased significantly in the last 10 years. This is because of an increase in the livestock population, overgrazing, lack of proper management and improvement of the grassland, and stone excavation. Due to these factors, the respondents said the communal grasslands were of poor quality. The condition of erosion was placed at moderate, but they said there was high degradation in terms of forage production decline. In the grasslands studied foliar cover ranged from 83.8% to 96.2% with bare ground cover ranging from 2.2% to 14%. Most plant cover comes from plant base cover (62.3% to 83.3%) and perennial grass cover (68.8% to 91.5%). Though not constant throughout the grasslands, sub-shrubs and perennial forbs cover ranges from 14% to 36.7%. In all communal grasslands assessed, the canopy height of all vegetation was <10 cm. The respondents indicated that there were about eight plants (grasses and browses) that important in the area, of which *Cynodon dactylon* is most resistant to heavy grazing according to respondents in the study.

Discussion

Communal grasslands have been one of the most important feed sources for livestock in the study area, but they are now facing many challenges that have resulted in their degradation. Competition over communal land resources has grown over the years (e.g. cultivation, woody plantation etc.). For example, through the agreement of the users, some part of the communal grasslands have been set aside for cultivation by landless. The respondents also indicated that size and productivity has decreased over last 10 years in most communal grasslands. In most communal grasslands there is no established management or governance body responsible for managing access and use. The users of most of communal grasslands have no responsibility beyond using it. In some cases, attempts have been made to protect the communal grasslands from privatization and exploitation by outsiders. Certification does not exist in most of the studied communal grasslands. Livestock productivity, (eg. milk) decreased over last ten years, but the number of livestock that using the communal grasslands have been increasing. Grasslands condition has declined in recent years, although severe degradation remain uncommon for large areas. It has been clearly indicated that the
communal grasslands in the highlands of Ethiopia are an important source of grazing for livestock and for maintaining other significant ecosystem services. The communal grasslands’ importance as feed sources ranked 3rd in this study (13.6% of feed), however, Benin and Pender (2002) found that communal grazing lands ranked 1st in the importance of feed sources in the highlands of Amhara region, while Haileselassie et al., (2012) depicted that 20% feed source is from communal grassland. This disagreement shows that communal grazing lands are dwindling over time in terms of importance, area, and productivity. The study area, being sheep production dominated, largely confirms Haileselassie et al., (2012). However, grazing management in communal grasslands could play a stronger role in sustaining livestock production. The status of the vegetation cover was generally good, but the canopy height of the vegetation was less than 10 cm in all communal grassland assessed, showing heavy use. In some cases, bare soil and unpalatable species encroachment indicate degradation due to heavy grazing. Livestock is vital for Ethiopian farmers’ livelihoods. As land is becoming scarce and most rainy season feed intake by livestock occurs during grazing on communal grasslands, degradation from heavy grazing negatively affects the livelihoods of farmers through decreasing livestock productivity. Well-managed grasslands reduce degradation by improving feed provision, which alleviates the grazing pressure on land. The grasslands that remain need to be protected for both socio-economic and environmental reasons. Good management is required to conserve these. To be most cost-effective this management needs to be the responsibility of the local communities – the grassland users. Incentives such as external support might be required in the initial stages, but it is anticipated that when users see the benefits of management, they will be more motivated to invest their own resources into this. Planting trees in these areas is not the solution. To achieve good grassland management, it is important to have a comprehensive management plan especially aimed at grass and other vegetation restoration. Stocking rates of livestock should also be considered and monitored. Respondents have also indicated that having certificates strengthening their security of access to the grasslands will increase incentives to invest in better management and raising productivity. As described, to date, most of the communal grasslands have no certificate of ownership. A community-based management system is required. This needs to be inclusive bringing in the different land and resource users, their positions, interests and needs. Agreement will need to be negotiated. Further understanding of the status and current management and governance (if any) is an important starting point. Local institutions for taking up these roles may include edir along with government-formed groups, among other models. A process such as participatory rangeland management (PRM) (e.g., Flintan and Cullis 2010) provides a strong framework for this. A review of PRM (Flintan et al 2019) concluded that PRM can improve rangeland productivity and strengthen governance and management of rangelands, including women’s empowerment. Hence, this study argues that where there is no proper management and governance in place for communal grasslands, these lands are likely to be much less productive than their potential and may lastly end up disappearing entirely.

Conclusion

The communally used grasslands of highland Ethiopia play an important role in the mixed livestock-crop livelihoods that are the norm. However, the grasslands are disappearing at an alarming rate due to change of use to agriculture or tree plantations amongst other. Those that remain are often heavily degraded, unmanaged and access uncontrolled. Very few of these grasslands are protected through land registration and certification. Where grasslands have been lost, grazing pressure increases elsewhere. There is an urgent need for protection of the remaining grasslands and the introduction and/or strengthening of good governance and management. Most importantly the governance and management of the grasslands needs to be led by community members, whose capacity, roles and responsibilities will need to be built. This will require external facilitation and support.

Acknowledgment

This work was made possible through funding from the CGIAR Research Program on Livestock. We also thank woreda experts from agriculture offices in Menz Gera and Menz Mama for their facilitation and involvement in site selection.
References


Gebreselassie, S., 2005. Recent Experiences in Land Rental Markets in Ethiopia


Tesfay, Y. 2010. Feed resources availability in Tigray region, northern Ethiopia, for production of export quality meat and livestock, Ethiopia sanitary and phytosanitary standards and livestock and meat marketing program (Sps-Lmm), Texas Aand M University System.


Yadessa, E. 2015. Assessment of feed resources and determination of mineral status of livestock feed in Meta Robi District, West Shewa Zone, Oromia Regional State, Ethiopia, A MSc thesis submitted to School of Graduate Studies, College of Agriculture and Veterinary Sciences

Land Users – Land Watchers

Stefánsson, J.H.1 & Marteinsdóttir, B1

1Soil Conservation of Iceland, Gunnarsholt, 851 Hella, Iceland.

Key words: Citizen science; land-users; monitoring; stakeholder engagement.

Abstract

GróLind is a collaborative project with the aim of monitoring Icelandic vegetation and soil resources. It was founded in 2017 by the Icelandic National Associations of Sheep Farmers, the Farmers Association of Iceland, Ministry of Industries and Innovation, and the Soil Conservation Service of Iceland. GróLind is a collaborative project and cooperation with stakeholders, such as the science community, landowners, and others, is a fundamental concept in the project.

In this project, the state of vegetation and soils are evaluated. Currently, a citizen science project is being developed within GróLind, in which land-users will annually monitor, using a mobile app, the conditions of the land they utilize. The monitoring will be based up on permanent photo-points and simple ecological measurements. These data will be used together with more detailed measurements done by specialists, to assess the state and changes in Iceland’s vegetation and soil resources.

Land users’ participation provides more extensive and accurate monitoring, both spatially and temporally. Cooperation between scientists and land users increases the flow of knowledge and trust between groups, ensuring that the knowledge gained in the project will be used for sustainable land management. Furthermore, the data will be used to develop research-based indicators for sustainable land-use that later can simplify the monitoring.

Background

Citizen involvement in scientific work has a rich history and its importance is gaining recognition as well as trust (Miller-Rushing, Primack, & Bonney, 2012). The main trend in the involvement is that the gathering of numerical data by the public which are then processed and analyzed by professionals. Citizen science projects where everyone can participate in research or monitoring work, regardless of their scientific background, is called citizen observatory. Nowadays, the citizen observatories take advantage of latest technology and the usage of smartphones in data gathering. Environmental monitoring is a good example of citizen observatory. Citizen contributes to the monitoring work with compilation of data which increases knowledge of the environment and environmental changes. These leads to better management strategies and increased quality of decisions and operations (Dickinson, Zuckerberg, & Bonter, 2010; Liu, Kobernus, Broday, & Bartonova, 2014; Tweddle, Robinson, Pocock, & Roy, 2012).

In Iceland, there has been little emphasize on terrestrial environmental monitoring, especially monitoring vegetation and soil resources. The monitoring has mostly been confined to areas subject to heavy industry, forestry, or land restoration (Visinda- og tækniráð, 2017) despite that most of Iceland can be defined as rangelands for sheep (Stefánsson et.al., 2020), and large parts of the country’s vegetation and soil resources are utilized in various ways e.g., rangelands, outdoor recreation/tourism, hunting reindeers and wild birds. Large part of the sheep rangelands of unstable, poorly vegetated and unproductive ecosystems (Marteinsdóttir et al., 2020) and many are badly degraded (Arnalds et al., 2001) at least partly due to unsustainable grazing practices (Barrio et al., 2018). These resources should, due to its scopes and variety of utilization, be well suited as a public observation project.

In order to increase the knowledge on Icelandic terrestrial ecosystems, including rangelands, the GróLind project was established in 2017. It based...
on an agreement between the Icelandic National Associations of Sheep Farmers, the Farmers Association of Iceland, Ministry of Industries and Innovation, and the Soil Conservation Service of Iceland. The project is run by the Soil Conservation Service of Iceland and funded until 2026, but an independent interdisciplinary science committee oversees the project. The project is still in its early phase, but now for the first-time stakeholders and scientist are working together to generate data that can be used for sustainable land management. In a land that is extensively used for sheep grazing and that has an history of land degradation it is surprising how little focus has been on gathering reliable data. The aim of the project is to establish a long-term monitoring program of the terrestrial ecosystem of Iceland as well as construct a set of indicators regarding sustainable land use. The monitoring methods are based upon ecosystem functions such as soil and site stability and biotic integrity. The methods include both remote sensing technique and ground measurements. The ground measurements are threefold, detailed measurements, general measurements, and citizen science measurements.

Public participation in GróLind’s monitoring improves traditional data collection and thus provides more extensive data and information. In addition, it increases participants’ knowledge, skills and interest in the subject and promotes better decision-making in social ecological systems (Shirk, 2012; Wehn, 2019). This project will be the first large scale citizen observation vegetation monitoring project in Iceland, but until now citizens observation projects have focused on avian research, glaciology and meteorological observation. In this paper we discuss the citizen science part of the GróLind project which has the main aim to increase cooperation and partnership between different stakeholders in regard to sustainable land management, as well as create knowledge on land condition in Iceland.

**Land users – Land Watchers**

Citizen Science project within GróLind is named Land Users-Land Watchers. As the name indicate the focus is to engage land users in monitoring. However, that does not exclude others from participate, such as landowners without livestock, travel associations, sororities and other interested groups and individuals. In this project, participants will set up a permanent monitoring point in an area that they use, or are particularly interested in, and monitor the condition of vegetation and soil with the help of a smart phone. Monitoring is expected to take place, at least every other year. Participants will learn how to monitor and to recognize the signs of degradation. The monitoring data will become a part of the data in GróLind’s long term monitoring program and participants will be able to access their own data at any time. The citizen observatory project was presented in the spring of 2019 at GróLind’s introductory and consultation meetings, with land users and stakeholders, held all over the country. There sheep farmers and others showed considerable interest in participating in the project. This is not surprising as there is a long tradition for the participation of the public and sheep farmers in various projects that The Soil Conservation Service of Iceland has organized. The project *Farmers heal the land*, that has been running since 1990, is a good example of this. In that project, farmers get support, in form of consultation, seed and fertilizers to do reclamation work on their own land. There is also a similar project running that supports groups of farmers to do reclamation work in the rangeland commons they use for sheep grazing during summer.

The methodology of Land users – Land Watchers is still under development and in the summer of 2021, a test group of farmers will test the project methods. After the test period the methods will be finalized, and the project will begin formally in 2022.

**Methodology**

The Land Users - Land watchers’ measurements should be quick, take no longer than 15 minutes and not require any expertise. At the same time, they must be linked to land conditions, be detailed enough to be used in the analysis of remote sensing data and be compatible to other monitoring data collected within the GróLind project. The monitoring should be done at least every other year, but participants can monitor their points annually or even few times over the year. The participants choose a monitoring site, subject to certain criteria. The site must be in a homogeneous area which is not cultivated. Restoration sites may be included but other cultivated land, e.g., forestry, meadows, fields, and green areas in settlements are not within the project. Participants must have a permit, from landowners, to conduct the monitoring. Measurement sites will be marked with a special pole provided by the project. The monitoring method include among others, photo points, step point transects to measure vegetation cover and bare ground and visual estimation of soil erosion, flowering, and vegetation cover. These methods are a simplified version of other monitoring methods done in the GróLind project and like those methods based up on methods developed to monitor rangelands in the USA (Pellant et al., 2020) and Australia (Tongway et al., 1995).
Participants will use a mobile app to record measurements. The application does not require an internet connection to collect information, but an internet connection is required to send the information to a web server’s database. The project database maintains all data collected by participants and when new measurements are submitted, the participant receives a standard report which summarizes the information collected and compares it to data from previous years. While anyone who is interested will be able to take part in the project, in the beginning a special emphasis will be placed on getting farmers to participate.

**Conclusion**

Incorporating land users in monitoring, gives them an unbiased platform to monitor how the land responds to their land-use. This should allow them to better adapt their land-use to the current land conditions. The project also gives participants the opportunity to be a part of the GróLind project, which will hopefully increase their interest and confidence in its results.

**References**


The role of indigenous knowledge in the effective collective management of the communal rangelands

Finca, A.; Linnane, S.; Getty, D.; Slinger, J.H

1Agricultural Research Council; 2Dundalk Institute of Technology; 3Delft University of Technology

Key words: Communal rangelands; Indigenous knowledge; Participatory GIS

Abstract
Numerous scientific studies have highlighted the complexities associated with the collective management of communal rangelands. To date, policy interventions in rangelands have largely ignored people’s traditional ways of managing, with adverse effects on rangeland productivity. Thus, local knowledge has not been considered in spatial planning, despite the fact that local rural communities are often repositories of key indigenous knowledge. Hence this study set out to evaluate the role of indigenous knowledge in the management of the communal rangeland in Cata and Guquka, now and in the future. This was achieved through the use of Participatory GIS (PGIS), specifically participatory mapping to analyse how the communities use and view their rangelands now and how this has changed over time, and whether this can form a potential resource for effective communal rangeland management in the future. Results revealed that Cata and Guquka participants held extensive indigenous and spatial knowledge in relation to their communal areas. However, the existing knowledge is not translated into effective management of the communal rangelands, instead it is trapped in the older generation. These findings were attributed to social challenges including an ageing population, lack of youth involvement, fear of livestock theft, lack of mutual trust amongst community members and lack of resources such as fencing, access to dipping tanks and government services, and financial constraints. Thus, factors inhibiting the use of the existing indigenous knowledge for effective management of the communal rangelands in Cata and Guquka are more social than environmental. This suggests that new policy approaches incorporating local people’s indigenous knowledge in spatial planning which takes into account their unique local situations and the relationships between people and their resources are necessary. When people feel like their voices are heard and opinions valued, the adoption and sustainability of policy-based interventions becomes less challenging. Therefore, indigenous local knowledge, if effectively harnessed, could form a key component in adaptive management of these communal rangelands.

Introduction
Numerous scientific studies have highlighted the complexities associated with the collective management of a common pool resource such as communal rangelands (Ostrom 1990, 2010; Bennett et al., 2013; Hae 2016). In fact, Hardin (1968) stated that “Freedom in a commons brings ruin to all”. Although Ostrom (1990) believed individuals are capable of successfully governing common pool resources, she also claimed that there are no universal solutions on how to organise the management of such common pool resources. However, successful governance arrangements have to take into account the unique local situation, and the relationships between people and their resource (Vetter 2013). Accordingly, such arrangements should be crafted on a case by case basis, taking local indigenous knowledge and spatial awareness into account (Reed et al., 2015). A useful and effective way of capturing indigenous knowledge is Participatory Geographic Information Systems (PGIS) which is a form of participatory mapping that uses GIS technologies in a manner that accommodates the needs and capabilities of the communities directly involved and affected by planned projects and programmes (Abbot et al., 1998). Wang et al., (2008) defines PGIS as a tool designed to reflect local people’s spatial knowledge.

Traditionally South African land management policies have not taken local knowledge into consideration, despite the fact that local rural communities are often repositories of key
indigenous knowledge (Bennett et al., 2013). This suggests that indigenous local knowledge, if present and effectively harnessed, could form a key component in adaptive management of communal rangelands.

This study aims to explore the local spatial knowledge of the Cata and Guquka communities located in the Eastern Cape Province of South Africa, using PGIS particularly participatory mapping (p-mapping) to understand and analyse how the communities use and view their rangelands now and how this has changed over time, and whether this can form a potential resource for effective communal rangeland management in the future.

Methods and Study Site
The participatory mapping exercise employed had two phases which included the initial hand drawn maps and the final community map with narratives. The locations and existence of the features identified on the hand drawn maps were validated through transect and virtual walks. The first phase of the p-mapping involving identifying and locating important landscape features including, amongst others, village boundaries, grazing areas, roads, rivers and dams, summer and winter camps, areas with good and poor grazing, areas with erosion and those with invasive alien plants. Participants were provided with Google Earth aerial maps showing their communal areas for visual reference and A1 paper to draw the features on using different colours and shapes. This phase was conducted with eleven and ten participants in Cata and Guquka respectively.

The second phase delved deeper into people’s knowledge of their rangelands and focused on eliciting narratives linked to specific features. A set of carefully designed questions prepared beforehand were used to lead the discussions which were based on the features and boundaries identified on the initial hand-drawn community maps. The second phase had thirteen participants in Cata and six participants in Guquka. In both phases there was representation in terms of gender and age.

Results
Hand Drawn Maps: Cata and Guquka
A range of common features were identified and drawn by participants from Cata and Guquka on the initial and final hand drawn maps during the participatory mapping exercise. Figure 1 shows the Final hand drawn maps prepared by the participants.
Narratives linked to features identified in Cata and Guquka communal areas

Three common themes emerged from the participatory mapping process and the narratives shared by the participants in relation to land use change and grazing namely:

(i) Social structure and perception of community well-being, in particular the effects of relocations and the underlying issues behind the abandonment of cultivation. The relocations were linked to the implementation of the Betterment planning and mostly affected Cata residents. These occurred between 1963 and 1964 and had resulted in a reduction of land allocated for settlements, arable plots and the communal grazing. Cata and Guquka participants attributed the abandonment of cultivation to the 1982/83 drought, cessation of the provision of tractors, seeds, fertilizer and working tools; health issues associated with ageing; lack of youth involvement, and absence of the boundary fence separating the arable fields from the residential areas resulting in livestock entering the arable and destroying the crops.

(ii) Grazing management strategies and rangeland condition including the location of the camps and the associated grazing quality of the camps. Summer and winter grazing camps were clearly marked and their names identified and recorded, suggesting that participants from both Cata and Guquka are intimately connected with their lands and possess a high level of knowledge in relation to them. In Cata, summer camps were all identified and delineated on the mountains beyond the indigenous forest and pine plantations, while winter camps were all located on the foothills and lowlands (Figure 1). Generally, the view of the Cata participants was that the quality of their entire grazing area has declined and is being overtaken by black wattle. On Guquka’s final community map, participants located the summer camps on the mountain above the pine plantation and the indigenous forest and placed the two winter camps within the area below the mountains (Figure 1). The participants reported the mountain summer camps and the forest winter camp as having good grazing when compared to the lowland and foothill areas (Figure 1).

(iii) Rangeland condition indicators - Three ecological issues were identified as contributing to the poor grazing quality of both the Cata and Guquka communal rangelands including invasive alien plants (Acacia mearnsii – black wattle and Vhachelia karroo – sweet thorn), soil erosion and grass species composition change. Information about the rehabilitation efforts for both the invasive alien plants and soil erosion were only shared by Cata participants. These included clearing of black wattle in 2003, 2015 and 2016, in areas close to the dams, with regrowth observed for areas cleared in 2015 and the rehabilitation of erosion gullies on either side of the river in 2007 and 2017. With regards to grass species composition change, grasses such as Cymbopogon dactylon in certain part of the communal grazing both in Cata and Guquka. The reason provided for this change in grass species composition included the prevalence of unplanned veld fires, drought and the fact that people are no longer using the grass for thatching their houses and therefore it is not harvested anymore.

Discussion and Conclusions

Local knowledge has been viewed by experts as inferior, untrustworthy and largely unstructured for decades (Golobić and Marušić, 2007). It is only in more recent years that the role of insights provided by local people in informing complex land use planning activities is gaining attention (Kasemor et al., 2003; Hessel et al., 2009; Moos, Struwig and Roberts 2010; McCall and Dunn 2012). This is largely due to the growing awareness of localised environmental issues which has prompted the need for the participation of local people in spatial planning. When expert’s knowledge and indigenous knowledge are incorporated into one process, successful and collaborative planning outcomes can be generated (Brown et al., 2014) and can co-evolve to mutual satisfaction (Rolston et al., 2017). Findings from the participatory mapping and PGIS have revealed that the people of Cata and Guquka do indeed have intimate spatial and temporal knowledge of their communal areas. They were clearly able to identify and locate key features and boundaries including those of the grazing camps that no longer exist. These features and boundaries were accompanied by shared narratives which included events, their periods and the effects they had on people’s well-being. The process has revealed that local people’s knowledge of their rangelands is extensive. However, this deep knowledge that the people of Cata and Guquka hold about their rangelands is not currently being translated into effective grazing management for their rangelands or towards policy implementation. In fact the knowledge the communities hold in relation to rangeland and livestock management is held within or ‘trapped’ in the older generation who find it difficult to transfer it to the younger generation. In Cata and Guquka, participants
revealed two key factors that they believe are impacting upon the optimal utilisation of the communal rangelands by livestock across both rangelands, i.e. ageing of livestock farmers and lack of youth involvement. This also suggests that the value placed on livestock farming in rural development is dwindling amongst the younger generation and strongly suggests that there is a need for new policy approaches that would restore and instil the value of livestock farming for rural well-being amongst young people. A good starting point should include mechanisms to transfer the existing knowledge banks between generations or find young people already investing in livestock farming and currently profiting from livestock production to act as community champions to make agriculture attractive again and motivate other young people (Mashala 2013). If nothing is done, this valuable knowledge may be lost which will have implications on rural well-being into the future.

In addition incorporating this local knowledge in policy planning and implementation is also important in ensuring that it is translated into effective management of the communal rangelands. Golobic & Marusic (2007) noted that ideally planning decisions and policy interventions are not supposed to be taken or implemented without the consent of the communities affected. According to Friedmann (1993), disconnect between planners and stakeholders often results in poor adoption of policies by the targeted groups. Indeed, the exclusion of indigenous knowledge in the development and implementation of plans and policies makes it difficult to solve people’s real problems in a sustainable manner. Moreover, people in Cata and Guquka have knowledge resources that could be vital in paving a way for restoration of rangeland productivity, improved livestock health and rural well-being. PGIS in particular, can allow this local knowledge from communities to be used in a meaningful way through translation into accurate digital maps with accompanying shared narratives. Inclusion of people’s indigenous knowledge in planning and decision making on their common resources, is known to make people feel valued and that their voices are heard (Wolff et al., 2019). When people know they are participating effectively, their opinions are valued and they are given an opportunity to contribute to the challenges they are facing, it improves the quality of decision making and makes adoption of policy-based interventions less challenging. It also increases the sustainability of the interventions.

**Acknowledgements**

Agricultural Research Council; Dundulk Institute of Technology (Center for Freshwater and Environmental Studies); Delft University of Technology (Faculty of Technology, Policy and Management), National Research Fund – Thuthuka Grant: PhD Track

**References**


CONCURRENT SESSION 5

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Ecohydrology and Plant Responses
Effects of thinning density on soil water content of alfalfa and David peach intercropping in the hilly Loess Plateau, China

Chen Z.X. 1; Yang X.L. 2; Wang G.H. 2; Shen Y.Y. 2

1 State Key Laboratory of Grassland Agro-ecosystems, Lanzhou University, Lanzhou 730020, P. R. China
2 College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou 730020, P. R. China

Keywords: intercropping; soil water storage; soil water deficit; Hilly Loess Plateau

Abstract
Intercropping alfalfa (Medicago sativa) between the four meters inter-row spacing of David peach (Amygdalus davidiana) is one of replantation practices at the Longtan catchment in Gansu province of the western Loess Plateau in the early 1980’s. However, both alfalfa and David peach are deep-rooted species and their intercropping results in excessive consumption of soil water in the hilly Loess Plateau. To alleviate this, we set up four density/intercrop treatments, which includes: David peach + alfalfa (PA), David peach (P), 60% David peach + alfalfa (60% P+A) and 60% David peach (60% P). TRIME was used to quantify the soil water content in 0 to 180 cm soil layers. We found that the deep layer (120-180 cm) soil water content of PA treatment was only 6.9%-8.7% during the growing season, which was close to the permanent withering point (6.5%). The soil water storage of shallow layer (0-60 cm) under P treatment was higher than the other three treatments during the dry season (April-June). Compared with the PA, the soil water storage of deep layer under the 60% P treatment increased by an average of 5.7%. This study concluded that the intercropping of alfalfa and David peach intensified the deep soil water deficit and reducing the vegetation density may be a good measure for the restoration of soil water.

Introduction
Soil water resources affect plant growth and plant distribution. The stability of plantations is mainly affected by soil water. The problem of deep soil desiccation caused by the strong transpiration of plantation affects the growth of vegetation (Jun et al., 2008). Thinning is the main technical measure for artificially promoting plant growth (Bhandari et al., 2021). Reasonable thinning can improve the soil water status of forest land and reduce the competition between plants to maintain the stability of plantations. Therefore, in this study, we chose the David peach (Amygdalus davidiana) plantation and alfalfa on the slope of Longtan catchment, Dingxi, the western Chinese Loess Plateau. The plants were used as research objects to monitor the changes of soil water content in plantation and grassland under different structural adjustment measures, aiming at clarifying the effects of removing alfalfa and thinning David peach on the soil water of plantation grassland. This survey is of great significance to the restoration and stability of vegetation in the semi-arid region.

Materials and Methods
This study was conducted in Longtan watershed (35°43′-35°46′N, 104°27′-104°32′E, ele. 1967-2168 m), Dingxi city, Gansu province China, belongs as the shallow gully Loess Plateau. The annual average temperature is 6.8°C, and the average annual precipitation is 386 mm (Yang et al., 2014). We chose a southeast slope where alfalfa planted between David peach rows over 15 years. Thinning density treatments were as follows: David peach + alfalfa (PA), 40% David peach was thinned + alfalfa (60% P+A), all alfalfa were moved only David peach remained (P) and 60% David peach (60% P): 40% David peach was thinned, alfalfa was moved, with four
replicates along the slope surface in July 2018. In one treatment, tubes were installed one in alfalfa field and two below the thinned David peach tree. The soil water content (SWC) was measured at 15 ds interval at layers of up to 180 cm in 20-cm increments below the soil surface using a time-domain reflectometry (TDR) moisture measurement system (TRIME, IMKO Micromodultechnik, Germany).

**Results**

At the beginning of growing season (May), the SWC under 60% P+A treatment was higher than the other three treatments in 20-60cm soil layers (Fig. 1). In May, August and October, the SWC in 80-160 cm soil layers under 60% P treatment was higher than the other three treatments. The soil water storage of 120-180 cm soil layer under 60% P treatment was higher than the other three treatments (Fig. 2). In the dry season (April-June), the soil water storage in the 0-60 cm soil layer under 60% P+A treatment was higher than the other three treatments.

**Figure 1:** Profile distribution of soil water content under different treatments in typical periods.

Figure 1: Maximum root conductance (Kmax) measured in A. gerardii (ANGE) and C. drummondii (CODR) grown under control and drought conditions in 1-year and 4-year burned tallgrass prairie. Shown are the mean (± 1 SEM) for control (grey) and drought (black) treatments.
Figure 2: Dynamics of soil water storage in different soil layers of Amygdalus davidiana plantation under different treatments during growing season

Discussion [Conclusions/Implications]
We found that 60% P+A treatment can restore the surface soil water (0-60cm) of Amygdalus davidiana plantation. And 60% P treatment had a positive effect on the restoration of deep soil water (120-180cm). It is due to that removing alfalfa and/or thinning David peach reduced the consumption of soil water on the slope by reducing vegetation density. Thinning David peach could reduce canopy closure that increased the penetration of rainfall (Zhu et al., 2015). The vegetation will extract a lot of soil water and reduce throughfall, which results in rapid development of soil water deficits. Consequently, measures to reduce vegetation density should be taken to reduce the soil water consumption of vegetation. Bréda et al., (1995) found that excessive density caused vegetation extract a lot of soil water and reduce throughfall, which results in rapid development of soil water deficits. Aiming at resolving the severe water shortage in alfalfa and David peach intercropping land, appropriate water management measures (e.g., thinning) should be taken to reduce excessive consumption of limited water resources. Our study provides valuable information for soil water management of artificial vegetation in the hilly Loess Plateau.

Acknowledgments
This work was jointly supported by National key Research and Development Plan (2017YFC0504603).

References


Plant root mass fraction response to soil resource limitation in the context of dry Mediterranean rangeland

Dovrat, G.1

1Department of Natural Resources, Newe Ya’ar Research Center, Agricultural Research Organization (ARO), Ramat Yishay, Israel.

Abstract
Root mass fraction (RMF) was proposed as a stable measurement of plant resource partitioning that can represent plant acquisition–conservation trade-offs. We examined the effects of soil resources availability on RMF of abundant annual plant species of water-limited rangeland. We used data from controlled experiments in which nine species were grown under variable water and nitrogen availabilities and their root and shoot biomass were examined at flowering time. In legumes we examined also presence of N₂-fixation. In all of the species, reduced water and/or nitrogen availability was associated with increased RMF. However, the magnitude of variation in RMF found between the resource availability treatments was different among the annual species. At the intra-specific level, plant size was negatively related to RMF. Finally, in legumes RMF corresponded to the species’ N₂-fixation status.

Introduction
Annual plant species are typical of water-limited environments, and are represented in high diversity in Mediterranean rangelands, in which amounts and distribution of rainfall are highly unpredictable and confined to a short season. During this limited growth period, the annual plants’ partition biomass between root and shoot in order to optimize resource capture (McConnaughay and Coleman 1999) and maximize fitness (Weiner et al., 2009). Thus, variation in the total biomass of annual plants at the end of the growing season reflects differences in resource capture and biomass production rate, whereas variation in biomass partitioning may reflect the adaptation and adjustment of species in their coping with variation in resource availability (Dovrat et al., 2019a). Previous works have shown that plant species respond to soil resource limitation by altering their biomass partitioning in order to better capture and preserve limited resources (see in Poorter et al., 2011). However, these works mainly focused on resource allocation physiology and did not deal with the biomass partitioning patterns of a particular plant assemblage.

Since the size and seed production of annual plant species are directly related to the environmental conditions prevailing during a defined growth period (i.e., one growth season), annual plant communities provide a unique opportunity to study patterns of resource capture and allocation in relation to environmental conditions. However, to date, only few empirical studies have examined the magnitude and patterns of biomass partitioning traits with respect to total plant biomass within and among plant species and under varying resource availability (Chanteloup and Bonis 2013, Nathan et al. 2016, Dovrat et al., 2019b). In recent works, we empirically studied the extent and pattern in which plant size is related to resource partitioning within and among key annual plant species and under varying resource availability (Dovrat et al. 2019a, Dovrat et al., 2020a).

Unlike root-to-shoot ratio, the use of root mass fraction (RMF) had been proposed as a stable measurement of resource partitioning (Poorter and Nagel 2000). In annual species, measurements of RMF at fixed phenological phases, such as flowering time, allow ontogenetically controlled comparisons among plants. In this work we examined RMF response within and among annual plant species of water-limited rangeland, under varying soil resource availability.

Materials and Methods
We have reanalysed annual species biomass production data. The selected species represent a range of sizes (Osem et al., 2004) and constitute a major portion of the plant abundance and
productivity of the annual plant community at Lehavim Long-Term Ecological Research Station. The climate in Lehavim is semi-arid with a short winter, and the average annual rainfall is 295 mm. The vegetation is characterized by sparse shrubland, with diverse herbaceous vegetation growing in large open patches between the shrubs. The herbaceous vegetation comprises mainly of annual species (130 identified species). The area has been used for livestock grazing (mainly sheep and goats) since prehistorical times (5000–8000 years, Perevolotsky and Seligman,1998).

Controlled experiments were conducted at the Volcani Center, Israel. Each of the species was grown as a single plant in a separate pot under three water levels (eight species) and two nitrogen levels (nine species). Destructive measurements of root and shoot biomass were conducted at flowering (81-86 days). Each treatment was performed in 5-10 replicates (pots). More details on the experimental methods can be found in Dovrat et al., (2018, 2019a). Biomass of shoots and roots was measured following oven drying (60° for 72 hours). Root mass fraction was calculated by dividing plant root dry biomass by the total dry biomass. Flowering time was determined for each treatment according to petal opening or, in the case of grass, according to the appearance of stamens.

In order to examine the effects of species, water availability and nitrogen availability, on plant total biomass and RMF, a Multifactorial ANOVA test was used. Basic assumptions for ANOVA tests i.e., normal distribution of error and homogeneity of variances, were examined using the Kolmogorov–Smirnov test and Levene’s test, respectively. Data not corresponding to these assumptions was mathematically transformed. All statistical analyses were conducted with the SPSS 25.0 software (SPSS Inc, Chicago, IL, USA).

Results
In all nine annual species examined, decrease in water and nitrogen availability caused an increase in RMF. Multifactorial analysis results showed significant effects of water and N availabilities on species’ RMF, as well as significant interspecific differences in RMF and total biomass. Interspecific differences in the extent of the response to N-availability were reflected through significant N×sp. interaction on RMF. Additionally, no significant N×water interaction effects were found, indicating an independent effect of water and N availabilities on RMF.

Discussion
Annual species respond to changes in soil resources availability and reorganize through resource partitioning, as we have presented here, via changes in RMF. Reorganization allows better use of available resources and maintenance of reproductive effort (Dovrat et al., 2019a). All studied species decrease in size and increase in RMF in response to decrease water availability. However the magnitude of variation in plant size as well as in RMF found along the soil-resource availability treatments was different among the annual species. This interspecific variation reflects a range of biomass allocation strategies present in the plant community of the studied water-limited rangelands site, which allows fast response to rainfall amount and distribution (Dovrat et al., 2020b).

Using soil resources manipulation, we demonstrated in recent works that annual species size (flowering size) was negatively related to root to shoot ratio at the intraspecific level, but no relationship was found between size and biomass partitioning at the interspecific level (Dovrat et al., 2019a). However, we found that species size was negatively related to stress resistance. This tradeoff between species size and stress resistance emerges as a consistent property of fundamental importance in shaping annual plant communities along resource gradients (Dovrat et al., 2019a). In another work we showed that RMF of annual Fabaceae species was higher in uninoculated (without bacterial inoculation) plants compared to N2-fixing plants. The root mass fraction was similar in inoculated plants of all species regardless of dramatic differences in nitrogen availability, and was not influenced by the different sizes of plants at flowering time (Dovrat et al., 2020a).

Biomass partitioning trade-offs can explain the presence and abundance of species along resource availability gradients and are primary drivers of community productivity patterns (Nathan et al. 2016). Future work is required to understand the importance of these mechanisms in plant community response to herbivory, as well as in invasive weed dynamics in these water-limited rangelands.

Acknowledgements
Many thanks to Sivan Golan and all Israel Plant Gene Bank staff for help with seed storage and germination. For all help with the experimental work thanks to Assaf Achtrak, Yiftach Katzir, Mor Ashkenazi and Yossi Moshe.
References


Rangeland rehydration: collaboration between land managers, government and private experts

Theakston, P.1; Pringle, H.J.R2; Mashford, L2

1Western Local Land Services; 2 Ecosystem Management Understanding™; Katalpa Station

Key words: rehydration; rain-ready; erosion; collaboration

Abstract

In the rangelands of New South Wales, Australia, many successful soil erosion control techniques have been developed. These techniques have been implemented by the Western Local Land Services (WLLS), rehabilitating 23,000 ha since 2004. However the focus was on degraded land with little regard to catchment dynamics and the threatening processes that were causing the degradation.

With the introduction of Ecosystem Management Understanding (EMU)™ in 2016, the focus was broadened to address grazing properties in a drainage ecosystem context. There is a focus on understanding landscape function and designing projects that address threatening processes.

With the integration of the WLLS and EMU approaches, effort is now put into saving threatened landscapes and resurrecting degraded landscapes. Both approaches have been integrated to restore soil moisture, reduce grazing impacts, restore calm water and save productive landscapes. In this process, landscape objectives and outcomes are identified and priority projects developed. A major benefit is the increased capacity of land managers to understand landscape processes and then to design and implement projects on their properties. This knowledge is allowing land managers to focus on being rain ready during droughts. The level of ownership has provided a forward looking focus for land managers, building resilience during drought.

Each grazing property will approach the same issue differently, depending on resources and preferences. Some approaches use earthworks while other approaches use soft filters to improve rainfall management. Earthwork techniques include champagne banks, waterponding, waterspreading, contour furrows and erosion control structures across roads. Soft filters are placed in flow lines to slow water and can be constructed from mesh, branches or rocks.

We tell this story through examples of projects and demonstrate the success of a collaborative approach to landscape rehydration.

Introduction

In the semi-arid rangelands of New South Wales (NSW), Australia, soil erosion control techniques have been developed to rehabilitate specifically degraded land. These techniques have been used successfully since the 1960s until present time and include contour furrowing, waterponding (Green, 1989), waterspreading (Quilty, 1972a) and erosion control along tracks/fencelines (Jolley, 2009).

The Western Local Land Services (WLLS) has been implementing these techniques, rehabilitating 23,000 ha since 2004. Due to this involvement, WLLS strengths are: 1) Expertise in layout of broad-scale rehabilitation projects, 2) Experience in numerous rehabilitation techniques, 3) Established landholder networks. Despite the success of the WLLS rangeland rehabilitation program, it was recognised within the organisation that it could be more effective in addressing large-scale degradation by improving its efforts in key areas. These included: 1) improving strategic planning and priority setting at a property level, 2) expanding focus to include drainage ecosystem dynamics, 3) expanding focus to include remnant highly productive landscapes rather than focussing on degraded landscapes, 4) building local capacity and community inter-dependence.
It was on this basis that WLLS approached Hugh Pringle of the Ecosystem Management Understanding (EMU)™ (Tinley & Pringle, 2014a) approach to help upgrade the Rangeland Rehabilitation Program. EMU was developed in Western Australia based on Ken Tinley’s empowering approach to consultation with land managers developed in southern Africa (Tinley & Pringle, 2002) and a shared training in physical earth sciences as well as biological sciences by its developers (Pringle & Tinley, 2003). The approach to rehabilitation is encapsulated in Key Principles and Steps in Catchment Repair in Arid Rangelands (Tinley & Pringle, 2006). Hugh Pringle has been working on landscape rehydration in NSW since 2016 with key strengths being: 1) focus on landscape dynamics and the importance of drainage ecosystems, 2) addressing degradation in a landscape and land manager directed, strategic manner, 3) building land manager capacity both on-property and as local knowledge networks. The inclusion of aspects of the EMU approach complements the WLLS approaches already established during decades of the NSW Soil Conservation Service. The enhancement has not been unidirectional and EMU has been enhanced by involvement with WLLS in improving historically degraded lands with inert but potentially productive soils. This paper narrates the successful and innovative journey of the three-way partnership.

**Materials and Methods**

WLLS is a government agency concerned with improving agricultural productivity and management of natural resources. The rangeland rehabilitation program, within WLLS, works with land managers and focusses attention on erosion control and improving water infiltration. It was recognised within the agency the rangeland rehabilitation program could be more effective in addressing large-scale degradation. WLLS contracted EMU to work closely with the program to improve and strengthen its effectiveness.

To start the collaboration within western NSW, WLLS organised a group of land managers to participate in the EMU approach. This group proceeded through the EMU process and developed priority projects. These priority projects aligned with the rangeland rehabilitation program’s objectives. Consequently WLLS offered funding to implement one of the priority projects. Implementation of the projects involves: project design, layout of works and construction. Implementation is a collaboration between all three parties (WLLS, EMU & land managers), each member specialising in different techniques.

A total of 6 groups have progressed through this process, totalling 30 land managers/businesses.

**Results**

A total of 30 land managers/businesses, covering 1.51 million hectares, have been involved in the collaborative approach between WLLS and EMU. This collaborative approach is an important part in strategically implementing landscape rehydration projects.

**Collaborative Rehydration Projects**

Projects are developed and implemented by integrating the key strengths of WLLS, EMU and the relevant land manager. One example of a collaborative project occurred on Katalpa, which is owned and managed by Luke and Sarah Mashford. The EMU approach emphasises land manager understanding of landscape processes, particularly in drainage systems. Through the EMU process, Luke and Sarah identified a dehydrated floodplain. In order to fix this issue, critical intervention points in the landscape needed to be identified. The land manager identified this critical point, which is the point in the landscape where a technique needs to be implemented for maximum rehydration and success. The resulting project used a diversion spreader bank (Quilty, 1972b) and waterponding. Photo 1 shows the project after completed earthworks and rain.

The Katalpa project involved earthworks, however this is not always the case. Projects are developed and implemented in a collaborative manner and accommodate the desires of the land manager involved. Each project has specific resources, preferences and capacity. A variety of techniques have been used, either from the EMU “toolbox” (Tinley & Pringle, 2013), WLL techniques or land manager developed techniques.
Photo 1: This area shows the critical intervention point of the floodplain rehydration project on Katalpa. Water is diverted out of an erosion gully onto the adjacent floodplain using a diversion bank and deposited via a waterspreading bank. The waterponds (U-shaped banks) rehydrate scalds. This project was identified via the EMU process, with the land manager identifying the critical location and constructing the earthworks. Solid blue arrow indicates concentrated flow; dotted blue arrows indicate low energy flow.

Photo 2: A variety of techniques are used in the identified priority projects. This sieve structure on Allandy protects the exit point of an ephemeral wetland. The innovative triangle-shaped design makes it robust and provides a protected niche for plant establishment. Blue arrow indicates flow direction.
Local Community of Practice

A major benefit of the collaborative approach is the increased capacity of land managers. Land managers have built a self-sustaining, local community of practice. This local community of practice is evidenced in several ways. Some land managers have purchased heavy earthmoving machinery to implement projects on their properties. The understanding they have gained in landscape processes and constructing earthworks has enabled them to become project implementation “experts” in their community. They take this skill onto neighbouring properties, becoming part-time earthmoving contractors specialising in rehydration projects. Also, a local aerial mustering pilot has participated in the WLL and EMU collaborative approach. He has gained a good understanding of landscape dynamics and functioning of drainage systems. While in the air mustering for neighbours, he is also conducting an informal aerial survey of key issues. Aerial survey is one of the key stages of the EMU process. In an informal way this pilot is providing an on-going platform for constructive conversations with land managers regarding rehydration projects. Many potential projects have been discussed in this way.

As a way of formalising and strengthening the local community of practice, a group of 20 land managers, covering 730,000 hectares, formed the Far West Rangeland Rehydration Alliance (FWRRA). The FWRRA has given members a forum to discuss land management issues, attract project funding, raise awareness of natural resource management issues and provide peer-to-peer support. This has been a success in building local capacity and community inter-dependence.

Discussion

This experience has demonstrated the power of collaboration when all parties combine their strengths. The foremost goal of this collaboration was to improve rangeland rehydration and build land manager capacity. This was successfully achieved and the three-way partnership will continue into the future. Furthermore, secondary beneficial outcomes have also been achieved.

Innovative approaches have been developed and implemented. In particular land managers have been at the forefront in developing innovative solutions. The example from Katalpa (see Photo 1) demonstrates this new approach. The diversion spreader bank, which was used at Katalpa, is a technique used by WLLS predominantly in the marginal cropping areas. The application of this technique at Katalpa was a result of the EMU focus on landscape dynamics and repairing drainage ecosystems. Through the EMU process the critical intervention point was identified, which enabled the diversion spreader bank to be used in a way not traditionally used. This project has been enormously successful, with the diversion spreader bank functioning correctly and causing the rehydration of approximately 1,000 hectares of floodplain. In other instances, land managers have been at the forefront in developing innovative solutions. For example, innovative sieve structures such as the one in photo 2 have been developed by land managers.

Another secondary outcome was the strengthening of local communities. This was evidenced during the recent extreme drought. During such times, community conversations usually centre on drought. The conversations can become depressing and feelings of hopelessness occur. In contrast, participating land managers had a positive focus on becoming “rain ready” for when the drought ended. Conversations were commonly around developing “rain ready” projects which would have immediate, tangible and positive effects. Land managers were talking about and actively supporting each other’s projects. The strengthened community continues to progress, even after drought conditions have improved.

The three-way collaboration has exceeded initial expectations and has strong support from all parties to continue into the future.

Acknowledgements

Terry & Georgina Luckcraft contributed photo 2 of the sieve structure which was developed by Terry.
References


Woody plant species composition and diversity in Rusinga Island, Homa Bay County, Kenya

Nyaga, M. N1; Mureithi, S. M1; Wasonga, V. O1; Koech, O. K1
Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi, P.O. Box 29053, Nairobi, Kenya

Key words: species diversity; species composition; Rusinga Island; Shannon’s diversity index; Woody plants

Abstract
Information on the state of woody vegetation of Rusinga Island is urgently needed in order to develop appropriate and effective conservation guidelines. Rusinga Island is an ancient historic area with numerous archeological sites and a bountiful of birdlife. However, the Island is characterized by highly degraded ecosystems from human disturbances such as cutting down of trees for fuel, construction poles, and overgrazing resulting in a remarkable degradation of flora, alteration of the ecosystems and loss of biodiversity. This study sought to determine the composition and diversity of woody plant species in Rusinga Island to understand the current status in order to develop appropriate and effective conservation measures since no such study has been conducted in the area before. Three hills (Ligongo, Agiro and Wanyama) were selected for sampling and demarcated into three study zones differentiated by the slope gradient and land use. A systematic random sampling approach was adopted to establish 98 sampling plots measuring 20 m x 20 m (400m²) for recording tree species and subplots of 10 m by 10 m within the main plots for recording shrubs and lianas across the three study zones at an interval of 200m. A total of 63 woody plant species belonging to 32 families and 51 genera were recorded, out of which 66.7% were trees, 31.7% shrubs and 1.6% lianas. The upper zones had significantly higher species diversity, species richness, evenness and abundance compared to the middle and lower zones. The lower zones depicted a lower abundance of plants and least similarities of species compared to the middle and upper zones. Development of appropriate conservation and management strategies is required in order to protect the woody plant resources from unsustainable human activities and to improve the natural diversity of the Island.

Introduction
Biodiversity around the World is under threat due to anthropogenic influences and climatic changes, with the former being the major contributor to biodiversity losses over the years (Foody et al., 2003). Most of the wild plant species are facing threats from overexploitation since very few are cultivated (Schippmann et al., 2002) in addition to the increasing extraction pressure. In particular, woody plant species are threatened in different parts of the World. It is estimated that 10% of all plant species are threatened with the highest rates being of woody species in the tropics (Tabuti 2012). Woody vegetation plays vital roles in safeguarding the environment and quality of life through the removal of pollutants, offsetting carbon emissions, shading and cooling (Gao et al., 2013). Despite their importance, the natural forests are diminishing under pressures of deforestation and other human interferences leading to land degradation causing Global environmental problems (UNCCD 2003).

Information on species composition and diversity of an area is necessary for informed management in terms of economic value, regeneration capability and ultimately to sustainable conservation of biological resources (Sarka and Devi 2014). However, no such analysis has been conducted on the floristic composition and diversity of woody plant species of Rusinga Island. Therefore, the present study sought to determine the composition and diversity of woody plant species in Rusinga Island to understand the current status in order to develop the most appropriate and effective conservation measures for the area.
Materials and Methods
This study was carried out in Rusinga Island (0°35’–0°44’ South; 34°11’–34°22’ East) in Homa bay County, Kenya stretching over 44 km$^2$ with an elevation between 1100 m and 1300 m above the sea level (Opiyo et al., 2007; Osoro et al., 2016). The daily temperatures range between 16 and 34°C and tend to be higher during the dry months of June and October (Homan et al., 2015). Rusinga Island receives an annual rainfall of 800 to 1000 mm with an unequal distribution over the year greatly influenced by relief and altitude. The Island has two rainy seasons, the short rainy season which starts from October to December and the long rain season which is the most important season starts from March and ending in June but the seasons are highly unpredictable and variable with some years characterized by prolonged dry periods (Opiyo et al., 2007).

Rusinga Island’s terrain is hilly and rocky with Ligongo hill being the main hill at the Centre of the island (Olanga et al., 2015).

Systematic sampling technique was used where three hills: Ligongo, Agiro and Wanyama hills were selected for sampling. The hills were further demarcated into three study zones: lower, middle and upper zones differentiated by the slope gradient, land use, and dominant vegetation types. On each hill, four transect lines cutting across the three study zones were demarcated starting from a common point at the apex of the hill and radiating to the four sides of the hill to the shores of the lake following the four compass directions (north, south, east, and west). In all study zones and hills, 98 sampling plots in total measuring 20 m x20 m (400 m$^2$) for recording tree species and one subplot of 10 m by 10 m within the main plot for recording shrubs and lianas were systematically demarcated at every 200 m interval.

Shannon-Wiener Diversity Index ($H'$) and Shannon’s evenness index ($J$) were used to estimate species diversity. Species richness was calculated using Margalef’s diversity index ($D$) (Clifford and Stephenson 1975) while the similarities in species was calculated using Sørensen’s coefficient ($SC$) (Sørensen 1948).

Results
A total of 63 woody plant species belonging to 32 families and 51 genera were recorded in all of the 98 sampled plots. Trees, shrubs, and lianas were represented by 42 (66.7%), 20 (31.7%) and 1(1.6%) species, respectively. Out of the total number of plants recorded, 78% were indigenous with only 22% of exotic species. Plant family Euphorbiaceae recorded the highest number of species (8 species) followed by Mimosaceae (7 species); Caesalpiniaaceae (6 species); Sapindaceae (5 species); Anacardiaceae, Apocynaceae, Bignoniaceae, Capparidaceae, Combretaceae, Flacourtiaceae, Meliaceae, Moraceae, and Tiliaceae (2 species each) with the other families represented by a single species.

The overall mean for Shannon’s diversity index in all the three hills and study zones was 2.23. There was a significant difference($P<0.001$) in species diversity among the three study zones with the upper zone of Ligongo recoding the highest species diversity (3.04) and the lowest recorded in the lower zone of Wanyama hill (1.21). A one-way ANOVA test revealed that there was no significant difference in species evenness among the three study zones ($P=0.203$). The Shannon’s evenness index ranged between 0.59 and 0.84 where the highest evenness index was recorded at the upper zones of Ligongo and Agiro hills (0.84) and lowest at the middle zone of Wanyama hill (0.59).

Woody plant species richness varied significantly in the three study zones ($P=0.004$) with the upper zone of Ligongo hill recording a significantly higher species richness (4.89) and the lowest richness recorded in the lower zone of Wanyama hill (1.03).

The highest species similarity index (Least dissimilarity) of 79.41 % was recorded between the upper zones of Ligongo and Agiro hill, while the lowest similarity index (highest dissimilarity) of 19.05 % was recorded between the lower zone of Wanyama hill and the upper zone of Ligongo hill.

Discussion
Plant family Euphorbiaceae recorded the highest number of species (8 species) followed by Mimosaceae (7 species). This is attributable to their adaptation to arid and semi-arid conditions which is a typical of Rusinga island. The Island is characterized by hot and dry climate relative to the rest of the country (Asinjo 2014). The upper zones were found to have more species richness followed by the middle zones and the least species richness was observed in the lower zones and the number of species found in any of the three study zones decreased from the lower zone to the upper zone. This was partially due to the activities that take place in different study zones thus causing the disappearance of woody species. For example,
the lower zone is close to the shores of the lake and it is mainly characterized by farmlands where farmers tend to uproot most of the woody plants for ease of cultivation.

Overall in all the hills and study zones an average of 2.23 Shannon’s diversity index was recorded in Rusinga Island. Ecosystems with Shannon-Wiener values greater than 2 are regarded as medium to highly diverse in terms of species (Giliba et al., 2011; Barbour et al., 1999), this implies that Rusinga island is a medium diversity ecosystem. The high species similarity index (Least dissimilarity) recorded between the upper zones of Ligongo and Agiro hill was probably due to the close proximity of the two hills whereas the high dissimilarity between lower zone of Wanyama hill and the upper zone of Ligongo hill may be due to lack of close proximity to each other, differences in altitudinal range, species composition and the levels of anthropogenic impact as observed by Tilahun et al., (2011) in a study conducted in Menagesha Amba Mariam Forest of Ethiopia. While conducting a study in Taita hills of Kenya, Omoro et al., (2010) found higher similarities in species in sites that were close to each other and attributed to similar mechanisms of dispersing seeds and similar soil seed bank.

Sustainable land management practices such as planting of multipurpose trees and protection of existing trees species in the lowlands and around homesteads and settlement areas is recommended for effective restoration of land cover as evidenced in highly disturbed areas with low plant cover within the lowlands and settlement areas than in less disturbed areas of the middle and upper zones of the study area.

Acknowledgements
The study was made possible through the financial support provided by Heini Staudinger für Afrika Association - Bahati Sasa, Vienna, Austria. We are grateful to Ms. Isabella Ostovary for setting up and coordinating the initiative to give master students the chance to undertake research on Rusinga Island, Badilisha Self-help Group for hosting the student at Rusinga Island and Books for Trees, the initiative that made the contacts. We thank the residents of Rusinga Island for their hospitality during fieldwork.

References


THEME 1: RANGE/GRASSLAND ECOLOGY

Topic: Fire ecology, Plant Responses and Management
Hydraulic responses of shrubs and grasses to fire frequency and drought in a tallgrass prairie experiencing bush encroachment

O’Keefe, K*; Keen, R; Tooley, E; Bachle, S; Nippert, JB; McCulloh, K

* Department of Ecosystem Science & Management, University of Wyoming, Laramie, WY USA; 1 Department of Botany, University of Wisconsin, Madison, WI USA; 2 Division of Biology, Kansas State University, Manhattan, KS USA

Key words: bush encroachment; drought; fire; tallgrass prairie; hydraulic traits

Abstract

The increase in abundance and density of woody plants in herbaceous ecosystems (i.e. bush encroachment) is occurring globally and is driven by reduced fire frequency, climate change, and the utilization of deeper, more reliable soil water by woody plants. Thus, a comprehensive understanding of the physiological processes through which woody and herbaceous plants use water will provide greater insight into the mechanisms of bush encroachment, as well as the trajectory of encroachment in a changing climate. Our objective was to assess how experimental changes in water availability and fire frequency impact belowground water-use traits in Cornus drummondii, the primary encroaching shrub within North American tallgrass prairies, and Andropogon gerardii, a dominant C₄ grass. Shelters that reduced precipitation by 50% (drought) and 0% (control) were built over mature shrubs growing in sites that were burned at 1-year and 4-year frequencies. We assessed the water transport capability of shrubs and grasses growing in each treatment by measuring the maximum hydraulic conductance ($K_{\text{max}}$) of entire root systems. We also assessed the vulnerability of shrub root segments to loss of hydraulic function by measuring the pressure at which 50% of the maximum hydraulic conductivity is lost ($P_{50}$). Grass and shrub roots had opposite responses to drought and these patterns varied with fire treatment. Grasses growing in drought plots had lower root $K_{\text{max}}$ than control grasses. Conversely, root $K_{\text{max}}$ did not differ significantly between treatments in shrubs. However, drought shrub roots were less vulnerable to water stress than control roots ($P_{50}=-1.5$ and -0.20 MPa, respectively). These results suggest that the ability of grass roots to use water declined with drought, while the ability of shrub roots to resist water stress increased with drought. Future work should investigate whether these drought responses are associated with altered root growth patterns.

Introduction

Bush encroachment, the increase in abundance and density of woody plants in herbaceous ecosystems, has occurred globally over the past century. This shift in land cover can have substantial impacts on the structure and functioning of grasslands and savannas, and previous work has shown that bush encroachment reduces vegetation diversity (Ratajczak et al., 2012), alters plant productivity (Knapp et al., 2008), reduces surface runoff and soil water recharge (Zou et al., 2018), and alters ecosystem-level water fluxes (Wang et al., 2010; Logan & Brunsell, 2015). Bush encroachment has been attributed to a variety of drivers including reduced fire frequency, increased grazing, and rising atmospheric CO₂ concentrations (Archer et al., 1995; Briggs et al., 2002). However, patterns and drivers of bush encroachment are often site-specific, which can complicate predictions of shifting grass-woody cover in different ecosystems. Predicting patterns and ecological consequences of bush encroachment is also complicated by an incomplete understanding of how woody and herbaceous species will function under future climate conditions. Improved predictions of future woody encroachment will therefore require a detailed understanding of the mechanisms facilitating the expansion of individual woody species in specific ecosystems, under both current and future climate conditions.

In the Great Plains region of North America, Cornus drummondii C.A. Mey. (roughleaf dogwood) is the primary shrub expanding across tallgrass prairie.
C. drummondii is native to tallgrass prairie but has increased in abundance and distribution over the past several decades due to reduced fire frequency in the region (Briggs et al., 2002). When burned infrequently, this clonal shrub produces large “shrub islands” that limit herbaceous growth in their understory and consequently prevent fire from carrying through an individual (Ratajczak et al., 2011). Additionally, C. drummondii is deep-rooted and uses deep stored water throughout the growing season. Consistent use of deep water allows this shrub to maintain static physiological rates despite seasonal fluctuations in temperature and precipitation (Muench et al., 2016), and also results in substantially higher rates and amounts of water-use than for co-occurring shrubs and herbaceous species (O’Keefe et al., 2020). Thus, the reliance of C. drummondii on a stable water source that is inaccessible to many other neighbouring species may also contribute to its recent expansion across tallgrass prairie.

Water stored deep in the soil is typically recharged annually from winter precipitation (Ransom, 1998) and may become reduced over time as drought intensifies and/or utilisation by woody species increases with ongoing woody encroachment (Vero et al., 2017). If deep water stores do become reduced, C. drummondii may experience water-limitation that impacts its physiology, growth, and survival. Furthermore, if C. drummondii is more susceptible to drought than co-occurring C₄ grasses, the cover and expansion of this species may be more limited in a warmer, drier climate than current models predict. However, how C. drummondii will respond to drought is not yet characterized. Information regarding this species’ susceptibility to drought will require a detailed investigation of the response of above- and below-ground hydraulic traits to experimental manipulations of precipitation.

Our objective was to assess how experimental changes in water availability and fire frequency impact water-use traits in C. drummondii and Andropogon gerardii Vitman (big bluestem), a dominant C₄ grass. Specifically, we assessed the following questions: (1) How do fire frequency and drought impact belowground maximum hydraulic conductance (a metric of ease of water flow through a tissue)? (2) Does root maximum hydraulic conductance respond differently to fire frequency and drought between C. drummondii and A. gerardii? (3) Do fire frequency and drought impact the vulnerability of C. drummondii roots to loss of hydraulic function?

Methods and Methods
Research was conducted during 2019 at the Konza Prairie Biological Station (KPBS), a Long Term Ecological Research (LTER) site located in the Flint Hills region of northeastern Kansas USA (39.1° N, 96.9° W). KPBS is a 3,487ha area of native tallgrass prairie that is divided into experimental watersheds, each of which receives various fire (burned every 1, 2, 4, or 20 years) and grazing (grazed by Bison bison, cattle, or ungrazed) treatment combinations. The landscape is generally dominated by a few C₄ grass species with many subdominant forb and shrub species (Smith and Knapp 2003). Frequent fire increases grass dominance, and infrequent fire promotes the expansion of native shrubs including C. drummondii (Ratajczak et al., 2011). This study was conducted in lowland locations of two ungrazed watersheds, one of which is burned every year and the other every 4 years. Rainout shelters were built in 2018 over mature C. drummondii growing with A. gerardii in each watershed. Seven shelters were built in each watershed, four of which reduced precipitation by 50% (drought) and three that did not reduce precipitation (control), resulting in 14 total shelters.

We measured maximum hydraulic conductance (Kₘₐₓ) in entire C. drummondii and A. gerardii root systems in August 2019. Kₘₐₓ is a metric of ease of water flow through a tissue with air bubbles that block water flow through water conducting cells (i.e. native embolisms) removed. Two clonal stems were measured on the same individual shrub per shelter and three individual grasses were measured per shelter. Each shrub stem or grass tiller was cut near the soil surface, attached to a high-pressure flow meter (HPFM), and root Kₘₐₓ was measured following Tyree et al., (1993) on a leaf area basis. We then analyzed differences in root conductance using a linear mixed effects model with species, fire treatment, and precipitation treatment as main effects, and shelter ID as a random effect.

We also assessed the vulnerability of individual C. drummondii roots to loss of function by measuring hydraulic vulnerability curves. C. drummondii roots were collected from each shelter and rehydrated in a 20 mmol KCl solution under a partial vacuum overnight. The following day, hydraulic conductivity was measured on fully hydrated samples using a hydrostatic pressure head. Hydraulic conductivity was then repeatedly measured as each sample was subjected to
increasingly negative xylem pressures using the centrifuge method (Pockman et al., 1995). The pressure at which 50% of the maximum hydraulic conductivity was lost \( (P_{50}) \) was then calculated for all curves within each water treatment*fire treatment group.

**Results**

![Figure 1: Maximum root conductance (K_max) measured in A. gerardii (ANGE) and C. drummondii (CODR) grown under control and drought conditions in 1-year and 4-year burned tallgrass prairie. Shown are the mean (- 1 SEM) for control (grey) and drought (black) treatments.](image)

Maximum hydraulic conductance \( (K_{max}) \) varied among grass and shrub roots, as well as precipitation and fire treatments (Figure 1). *A. gerardii* had greater root \( K_{max} \) than *C. drummondii* \( (p<0.05) \), particularly in annually burned plots. Additionally, *A. gerardii* growing in the annually burned control plots had greater root \( K_{max} \) than annually burned grasses in the drought plots \( (p<0.05) \). Grasses growing in drought plots had lower root \( K_{max} \) than control grasses, particularly for 1-year burned plots. Conversely, root \( K_{max} \) was somewhat greater in drought shrubs compared to control shrubs for both burn treatments, but this trend was not significant \( (p>0.05) \). Shrub drought roots were also less vulnerable to water stress than control roots \( (P_{50}=-1.5 \text{ and } -0.20 \text{ MPa}, \text{ respectively}) \). Shrub root vulnerability did not differ across fire treatments.

**Discussion**

We show that *A. gerardii*, a dominant \( C_4 \) grass in tallgrass prairie, has greater root \( K_{max} \) than the encroaching shrub *C. drummondii* in an annually burned watershed. This result is unsurprising given that \( C_4 \) grasses have extensive, fibrous root systems in shallow soil that can efficiently utilize available water and outcompete co-occurring species (Kitchen et al., 2009; Ma et al., 2018; Xu et al., 2015). Additionally, frequent fire increases grass dominance (Hartnett et al., 1996; Collins and Calebrese 2012) and grass root biomass (Johnson and Matchett 2001), which may increase the overall efficiency of water uptake by grass root systems (i.e., promote the higher \( K_{max} \) that we observed in annually burned grassland). We also observed a significant decline in grass root \( K_{max} \) in our drought treatment, suggesting that the competitive ability of grasses to use water may decrease in a warmer, drier climate. If so, grass productivity may decline in the future with concomitant impacts on grassland biogeochemical cycling.

Conversely, *C. drummondii* root \( K_{max} \) did not differ between treatment contrasts. However, individual *C. drummondii* roots were less vulnerable to water stress when grown under drought compared to control conditions, which may be associated with shifts in root microanatomy in response to water limitation. Together, these results indicate that *C. drummondii* water use is not necessarily impacted by fire frequency but may be altered by future drought. Under future drought, *C. drummondii* will likely have root systems that will be more tolerant to low soil water availability.

These results are important because they suggest that the unique physiological responses of \( C_4 \) grasses and encroaching shrubs to drought may alter their functioning, competitive ability, and cover/distribution in a future climate. Grasses that exhibit lower root \( K_{max} \) under extended dry conditions may experience reduced aboveground growth and competition for belowground resources, which may ultimately reduce their presence in tallgrass prairie. Conversely, encroaching shrubs that exhibit reduced vulnerability to water stress may increase in cover and distribution in the future. Thus, *C. drummondii* physiology may facilitate its ongoing encroachment across tallgrass prairie in the Great Plains (O’Keefe et al., 2020). Future work should investigate whether these drought responses are associated with altered root growth patterns (e.g., root biomass and anatomical traits), and if these drought responses impact ecosystem processes in tallgrass prairie.

**Acknowledgements**

Funding was provided by the Department of Energy Terrestrial Ecosystem Science Award DESC0019037, the Division of Biology at Kansas State University, and the University of Wisconsin-Madison College of Letters and Science. The Konza Prairie Biological Station provided logistical support and the maintenance of the long-term fire and grazing treatments.
References


Prescribed fire plus grazing horses: A sustainable model to decrease fire hazard in a mountain landscape

Torres-manso, F.; Pinto, R.; Marta-Costa, A.; Fernandes, P.; Fernandes, M.

1CIFAP/CETRAD/UTAD; 2CETRAD/UTAD; 3DESG/CETRAD/UTAD; 4CIFAP/CITAB/UTAD; 5CEGOT

Key-words: fire effects, horses, vegetation cover, volume, valorization.

Abstract

The mountain landscapes of northern Portugal have been modified through rural depopulation and the absence of rangeland management. As such, increased above-ground biomass and higher fire hazard resulted, as well as decreased ecosystem biodiversity. The objectives of the OpentoPreserve Interreg SUDOE project are to evaluate the effects of the combined use of prescribed fire with grazing horses, and also to develop strategies of socio-economic valorization of this model. Concerning the evaluation of prescribed fire and grazing effects, the experimental design consisted of three plots in the Natura 2000 Alvão/Marão Site, respectively Control, Fire x Grazing, and Fire. The Fire plots were burned in early spring and vegetation percent cover and height were measured in all plots in late spring. We have implemented four transects in the three different plots, used the line intercept method and subsequently estimated vegetation volume. This methodology is also applied on Forestation of Agricultural Land with More Silviculture, Silvopasture, Innovation and Value project. Concerning socio-economic valorization, the stakeholders related to the native horse breed, were interviewed and a focus-group was held. The study intends to identify both the benefits resulting from the adoption of a management system that includes the native horse breed, named Garrano, and the main weaknesses related to environmental, economic and social sustainability. Initial results for total vegetation in each plot show a high reduction in vegetation percent cover and its volume in the burned plots (33.5% and 268.3 m$^3$ ha$^{-1}$) in comparison to the control plot (183.7% and 12862.5 m$^3$ ha$^{-1}$). Furthermore, a fast recovery was observed in July, mainly of the *Pterospartum tridentatum* shrub species. Interviews and focus-group results shows the important role of these grazing animals in vegetation control as well as in other ecosystems services, involving an environmental and a socio-economic dimension. A strategy to value contribution to the economy of agricultural holdings has been proposed.

Introduction

The mountain landscapes of Portugal have been modified through rural depopulation and the absence of rangeland management. A number of asymmetries that reflect development inequalities can be observed in Portugal, particularly between the coast and inland regions, with devastating consequences for the economy of the latter territories. These consequences mainly result from the migratory phenomenon, which is increasingly contributing to depopulating inland regions, demographic imbalances, population aging, and landscape abandonment. In addition, agriculture becomes impracticable for older people nowadays. This phenomenon has implied an increase of high and dense shrublands, promoting the accumulation of biomass fuel, which is associated with high fire hazard. Several authors (Almeida and Moura 1992, Mather and Pereira 2006, Ruiz-Mirazo and Robles 2012, Mancilla-Leytón et al., 2013) have shown the existence of larger burned areas in the municipalities with the highest emigration. According to Bengtsson et al., (2000) it is important to understand natural disturbance dynamics and also their relationship with human disturbance. These authors refer how management practices are important to preserve biodiversity in human-influenced landscapes and ecosystems. In fact, European forests evolved and adapted under both natural and human
disturbance regimes and in this context, a good management of fire and grazing are important for the ecosystems conservation.

The objectives of the OpentoPreserve Interreg SUDOE project are to evaluate the effects of the combined use of prescribed fire with grazing by horses, and also to develop strategies of socio-economic valorization of this model. This article aims to demonstrate how Garrano horses can have a potential role to the sustainable landscape management, preventing wildfires.

**Materials and Methods**

One of the pilot experiences from the OpentoPreserve project is placed in the north of Portugal, specifically at the Natura 2000 Network Alvão/Marão site (lat: 41º17'47” N, 7º53’53” W) in a commonland area of 11 ha. The average elevation is 850 m, in a 15-20% slope with a S-SW aspect. The soil is from schists-grauvaqic origin, local mean annual rainfall ranges from 1400 to 1600 mm and mean annual temperature from 10º to 12ºC.

The experimental design consists of a delimited area where 4 ha were burned using prescribed fire in the early spring of 2019. There, two plots (3 ha and 1 ha) were established, respectively for combined and monitored practices of prescribed burning and grazing. The experimental design comprises a fire and grazing plot (3ha) (F*G), a fire plot (1ha) (F), and a control plot (0, 2 ha) (C). The first two plots were fenced and in the F*G there are 3 Garrano breed horses in permanent grazing, which have been introduced in March 2020. The animals are supplemented with hay and their body condition is measured weekly.

At the end of spring 2019, after prescribed fire and before grazing, 4 permanent transects were established and georeferenced in the three different plots and vegetation monitoring was started using the line transect method (Canfield 1941) for estimating vegetation cover, height, and phytovolume. The same method was applied in the spring of 2020.

Concerning socio-economic valorization, the stakeholders, including breeders, companies, and associations related to the Garrano horses were interviewed and a focus-group with several agents and companies was held. There were listed some ideas for the implementation of valorization strategies for this breed.

**Results**

**Spring 2019**

Mean structural characteristics for the vegetation in each plot are presented in Table 1, highlighting the high reduction from C to F*G and F treatments in cover, height, and volume. In Spring 2019, F*G and F can be considered similar treatments because F*G had not yet been grazed.

The dominant species in the control plot were the legume shrubs *Pterospartum tridentatum* (78%) and *Ulex minor* (38%) and there were also Ericacea shrubs as *Erica umbelata* (32%) and *E. cinerea* (30%). *Pterospartum tridentatum* (25%) and *Ulex minor* (10%) were the main species found in the fire plots.

**Table 1: Vegetation structure per treatment in the 2019 inventory**

<table>
<thead>
<tr>
<th></th>
<th>July 2019</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cover (%)</td>
<td>Height (cm)</td>
<td>Vol.(m³/ha)</td>
</tr>
<tr>
<td>Control</td>
<td>183.75</td>
<td>70.03</td>
<td>12862.50</td>
</tr>
<tr>
<td>Fire&amp;Grazing</td>
<td>40.00</td>
<td>8.99</td>
<td>359.47</td>
</tr>
<tr>
<td>Fire</td>
<td>32.50</td>
<td>10.18</td>
<td>330.89</td>
</tr>
</tbody>
</table>

**Spring 2020**

What it can be highlighted concerning vegetation cover and volume is the persisting great difference between the control plots and the other plots (Fig. 1 and Fig. 2). In the Spring of 2020, the difference in total vegetation cover and volume between F and F*G is mainly explained by the consumption of grass by the horses. In species or groups of species, there are no significant differences between treatments.
Figure 1: Dynamics of vegetation cover with fire and grazing (2019-2020)

Figure 2: Dynamics of phytovolume with fire and grazing (2019 -2020)

Socio-economic valorization

The results of the interviews and the focus-group shows the abilities of the breed as well as its constraints and potentialities were identified. The most socially valued proposals involve the payment of services to farmers whom, in addition to recognising these horses as historical heritage, develop activities which contribute to the maintenance of the Garrano population and to its environmental externalities. Concerning the environmental dimension, the participants understand that the training and awareness of breeders on the multifunctional potential of the breed is relevant. They should be aware of the importance these horses may have in fire prevention. Finally, the evaluation of the economic dimension brings out three potentialities that could have a greater impact: the valorization of the Garrano as an endogenous resource in the area of tourism; the recognition of the breed as historical and cultural heritage and the payment of services to breeders who develop activities with the Garranos.

Discussion

It is important to stress the effect of fire on the cleaning of dense and ageing shrubby vegetation. This intervention allowed the regrowth of grasses as well as new shoots of shrubs, providing grazing by horses. The quick recovery of *Pterospartum tridentatum* in burned plots was already expected. Similar results were found in previous studies remarking also the good nutritive value of crude protein and digestibility of new *Pterospartum*
tridentatum shoots (Rego 1986, Torres-Manso 2005).

However, in regards to the reduction in cover and phytovolume by grazing it is early to have consistent results at this stage. One of the reasons is possibly the low livestock density, and the other is that more time is needed to reach conclusive findings in this type of study.

The valorization of the Garrano as an endogenous resource in the ecotourism allow to a strategy concerning the wild horse watching. This strategy involves the dimensions of sustainability.

Acknowledgements
This communication is funded by the FTA+siv project – “Projeto Florestação de Terras Agrícolas com Mais Silvicultura, Inovação e Valor” [Forestation of Agricultural Land with More Silviculture, Silvopasture, Innovation and Value], co-financed by the Fundo Europeu Agrícola de Desenvolvimento Rural (FEADER) and by the Portuguese State under the Action 1.1 “Grupos Operacionais”, integrated in Medida 1. «Inovação» from PDR 2020 – Programa de Desenvolvimento Rural do Continente.

This research was only made possible by the fact that it was integrated in the Interreg Sudoe SOE2/P5/E0804 “OpentoPreserve” project, by the European of Regional Development Fund (FEDER); CETRAD/FCT – Portuguese Foundation for Science and Technology under the project UIDB/04011/2020.

References


Modelling grazing and burning in communal rangelands to help understand trade-offs between production, carbon, and water

Hawkins, H-J; Moradzadeh, M; Vermeire, M-L; Farai Chikomba; Wu, L

1Conservation South Africa, 301 Heritage House, 20 Dreyer Street, 7735, Claremont, Cape Town, South Africa; 2Department of Biological Sciences, University of Cape Town, Private Bag X1, 7701, Rondebosch, Cape Town, South Africa; 3 Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK; 4IRD-CIRAD-IPME, University Montpellier, Montpellier, France

Key words: climate; ecosystem services; grasslands; process-based model; South Africa.

Abstract
Rangelands cover more than 80% of South Africa’s land area, providing critical ecosystem services, livelihoods and cultural values related to livestock. Communally owned rangelands are often overgrazed and subject to runaway fires but lack of data limits our understanding of how these threats impact production. In this transdisciplinary project, we use models to test hypotheses and predict future scenarios as a planning tool for resource-poor communal farmers. We think that moderate grazing and fire regimes will increase overall production and carbon sequestration with uncertain trade-offs for water and nutrient cycling. To test this, we trained two process-based biogeochemical models (DAYCENT and SPACSYS) with individual merits to simulate known fire returns and grazing pressures on a 40-year old long-term ecological research grassland site, and validated models with data from Mvenyane, a nearby communal livestock grazing area. DAYCENT and SPACSYS simulated observed soil organic carbon well, while accuracy for aboveground herbaceous biomass differed between models. DAYCENT projected that soil organic carbon could increase by ca. 1000 g C m⁻² over ten years or 1 t C ha⁻¹ yr⁻¹ with moderate increases in biomass and no change in water fluxes when changing from continuous high pressure to moderate pressure grazing in a two-camp rotation, with or without fire. These and other scenarios, including future climate projections, will be used to evaluate biophysical and social trade-offs so that sustainable land use plans can be created in Mvenyane and the wider rangeland community.

Introduction
Rangelands cover more than 80% of South Africa’s land area, providing critical ecosystem services, livelihoods and cultural values related to livestock. Rangelands evolved with both herbivory and fire and are essential to create landscape heterogeneity and cycle nutrients. Communally owned rangelands are often overgrazed and subject to runaway fires but lack of data limits our understanding of how these threats impact production. Poor management is associated with loss of both traditional practices and reduced agricultural services during and post the Apartheid era (1948-1994). The uMzimvubu Catchment Partnership endeavours to support resource-poor communal livestock farmers to restore rangelands and livelihoods linked to livestock via Conservation Agreements (CA), which include the re-introduction of *maboella*, a traditional two-camp rotation where areas are alternatively ‘rested’ or grazed during the austral summer growing season. To date, various combinations of grazing and fire have not been introduced to CAs due to lack of data on how this will change production, soil carbon, water fluxes, and thus risk to farmers. For this reason, we used two ecosystem-level models to test hypotheses and predict future scenarios. We expected that moderate grazing and fire regimes within a two-camp rotation would increase overall production and ecosystem functions, including carbon sequestration via pyrogenic organic carbon, with uncertain trade-offs for water fluxes, while continued unplanned, continuous heavy grazing pressures would reduce ecosystem services and livelihoods, exacerbated by climate change. We intend model outputs to act as scenarios that will aid decision-making and co-development of land use plans with community members.
Materials and Methods

The 40-year-old Brotherton Long Term Ecological Research (LTER, uKhahlamba-Drakensberg Park) site is ca. 180 km north of the area of interest, Mvenyane, a communally owned rangeland area in the Grassland Biome of South Africa. The sites have similar climate, soil, and vegetation characteristics but different management and herbivore types (Table 1). Model uncertainty was evaluated by training and testing model predictions with the Brotherton and Mvenyane data sets, respectively (Table 1). Two ecosystem-level models were used, DAYCENT (‘savanna’ module, v.1, 2018) developed by Parton et al., (1998) and Del Grosso et al., (2009), and SPACSYS (Wu et al., 2007; 2019). The SPACSYS model simulates plant growth and development, soil C, N and P cycling, water fluxes and energy transformation, animal growth rates, milk yield, energy requirement for maintenance, production, growth and activity, excretion and gaseous emissions based on livestock breed, climate, soil and feed quality and quantity. The DAYCENT model simulates similar processes except animal production. Training model inputs were derived from the nearby Mike’s Pass weather station, field collections (soil pH, bulk density, texture, field capacity, root and foliar organic carbon, soil organic carbon (SOC) fractions; herbaceous biomass), remote sensing (NDVI, normalized difference vegetation index via Copernicus Sentinel data [2019] for Sentinel data on the Google Earth Engine platform), literature (wildlife counts) and the SPAW model (wilting point, hydraulic conductivity) using field soil texture (Saxton, 1986). Climate data for the test data set was derived from the nearby Kokstad weather station for periods relevant to validation data (2009-2019), and from modelled climate data for dates prior to 2009 (Copernicus Climate Change Service [2017] via the Google Earth Engine platform). Other test data were derived from field collections (herbaceous biomass, SOC, livestock counts) and beta SoilGrids (SoilGrids 2019). We assessed model accuracy and fit using the coefficient of determination / adjusted R$^2$. The pre-condition for the 2019 validation year and future scenarios was an overgrazed mixed C3/C4 grassland with a three-year fire return. Scenarios from 2020-2030 were created using the observed weather for 2009-2019 and various management options.

### Table 1: Site characteristics of the Brotherton Long Term Ecological Research (LTER) site and the Mvenyane communal rangeland area. Abbreviations: MAT (mean annual temperature); MAP (mean annual precipitation); and LSU (livestock unit).

<table>
<thead>
<tr>
<th>Site</th>
<th>Brotherton LTER (training data)</th>
<th>Mvenyane communal area, amaHlubi tribe (test data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Established</td>
<td>1980</td>
<td>ca. 1800</td>
</tr>
<tr>
<td>Location</td>
<td>28.96°S; 29.26°E</td>
<td>30.57°S; 29.02°E</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>1890</td>
<td>1340</td>
</tr>
<tr>
<td>MAT (°C)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>MAP (mm)</td>
<td>1075</td>
<td>874</td>
</tr>
<tr>
<td>Soil type</td>
<td>Rhodic and Haplic Acrisols</td>
<td>Haplic Acrisols</td>
</tr>
<tr>
<td>Biome</td>
<td>Grasslands</td>
<td>Grasslands</td>
</tr>
<tr>
<td>Vegetation type</td>
<td>uKhahlamba Basalt Grassland (Gd7)</td>
<td>East Griqualand Grassland (Gs12)</td>
</tr>
<tr>
<td>Management</td>
<td>Burning trial in wildlife reserve; controlled 1-3 year fire returns</td>
<td>Communal livestock grazing area; unplanned grazing and 3 year fire return (average 2001-2019)</td>
</tr>
<tr>
<td>Predominant herbivores</td>
<td><em>Alcelaphus buselaphus caama</em>, <em>Damaliscus pygargus phillipsi</em>, <em>Ourebia ourebi</em>, <em>Pelea capreolus</em>, <em>Redunca arvundinum</em>, <em>Redunca fulvorufa</em>, <em>Tragelaphus oryx</em></td>
<td><em>Bos taurus</em>, <em>Ovis aries</em>, <em>Capra aegagrus hircus</em></td>
</tr>
<tr>
<td>Stocking rate</td>
<td>0.02 (appropriate wildlife stocking)</td>
<td>0.25-1.5 (tending to overstocking)</td>
</tr>
</tbody>
</table>

1IUSS Working Group WRB, 2015; 2Mucina and Rutherford, 2006; 3Rowe-Rowe and Scotcher, 1986; 4Conservation South Africa, pers comm.
Results
Both models accurately simulated herbaceous biomass of the LTER site, e.g. $R^2 = 0.5$ to 0.8 for various grazing and fire treatments in DAYCENT, while phenological patterns of grassland growth were also acceptably simulated (data not shown). Using the calibrated parameters from the LTER site with the climate and soil characteristics in Mvenyane, we found that measured and modelled biomass was similar for unrested areas (DAYCENT) or rested areas (SPACSYS). The DAYCENT simulation was accurate for both rested and unrested areas because the ‘rested’ area was, in reality, frequently trespassed by grazing livestock belonging to non-CA communities neighbouring Mvenyane, and biomass did not increase as expected (Fig. 1A). Supporting this, the 2019 NDVI time-series was near-identical for the unrested and ‘rested’ areas ($R^2 = 0.90$, data not shown). DAYCENT accurately simulated SOC and was similar for both rested and unrested areas, varying little between grazing treatments, while SPACSYS overestimated SOC especially in rested areas (Fig. 1B). Future scenarios using DAYCENT indicated that SOC could increase by ca. 1000 g C m$^{-2}$ (10 t ha$^{-1}$) over ten years or 1 t ha$^{-1}$ yr$^{-1}$ with a change in management from continuous high pressure grazing to moderate pressure grazing in a two-camp rotation, with or without fire, while the SPACSYS model indicated a similar end-point SOC for low-moderate grazing pressures (Fig. 2).

Figure 1: Aboveground herbaceous biomass (A) and soil organic carbon (B) for modelled and measured data in the Mvenyane communal livestock area. The pre-condition for model simulations was the unrested state in both treatments.
Figure 2: Simulated soil organic carbon (200 mm depth) from DAYCENT and SPACSYS with various grazing and fire regimes in the Mvenyane communal livestock area over a ten-year period. Abbreviations: LM (low-moderate grazing pressure); H (high grazing pressure). The pre-condition was the unrested state or Continuous grazing [H].

Infrequent moderate fires did not change SOC (Fig. 2). Biomass increased but water fluxes did not change with changed management from high to moderate grazing pressure (data not shown).

Discussion
DAYCENT and SPACSYS have individual merits, e.g., SPACSYS can simulate exact stocking rates and DAYCENT can simulate fire (SPACSYS must apply a full harvest event to simulate fire, i.e., fire simulations are uncertain). Data revealed that so-called rested areas are being grazed, requiring better commitment to CAs and communication with non-CA communities neighbouring Mvenyane. As expected, predicted scenarios indicated that continuous, high pressure grazing reduced both primary production and SOC compared to lower pressure grazing, either with continuous grazing (SPACSYS) or a two-camp approach (DAYCENT). Two-camp or season-long rotation has the known advantage of maximally utilizing rangelands (increasing animal distribution) with little effort (Briske et al., 2011; Venter et al., 2019). Small increases in aboveground herbaceous biomass (ca. 100 kg ha⁻¹ or 5 g C m⁻²) have been found after clearing of alien vegetation in Mvenyane (Vundla et al., 2020) while our simulated change from high to low-moderate grazing pressure indicated a tripling at peak growing season within one year. This prediction seems reasonable given that the herbaceous biomass on protected areas and well-managed commercial private farms in the district is three times that of communally farmed areas (Nel et al., 2013). We also predicted that SOC could increase by ca. 1 t ha⁻¹ yr⁻¹ with a change in management from continuous high pressure grazing to two-camp and low-moderate grazing pressures. These and other scenarios, including future climate projections, will be used to evaluate biophysical and social trade-offs so that sustainable land use plans can be created in Mvenyane and the wider rangeland community.

Acknowledgements
We thank Conservation South Africa, Ms Sue van Rensburg (South African Environmental Observation Network), Prof. Kevin Kirkman (School of Life Sciences, University of Kwazulu-Natal), and Ezemvelo KZN Wildlife (EKZNW) for facilitating this work, as well as the Agricultural Research Council-Climate, Soil and Water (ARC-ISCW) and EKZNW for weather data. Research was supported by the Biotechnology and
References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Water Stress and Water Use Efficiency
Effect of drought stress on fibre digestibility of corn for silage

Ferreira, G.1; Teets, C.L.1; Kingori, A.M.2; Ondiek, J.O.2

1Department of Dairy Science, Virginia Tech (USA); 2Department of Animal Science, Egerton University (Kenya)

Key words: climate change; drought; fibre digestibility

Abstract
Limited information exists about the impact of drought stress on corn silage digestibility. The objective of this study was to determine the effect of irrigation on in situ NDF digestibility of corn tissues grown under controlled conditions in a greenhouse. Five commercial corn hybrids were planted in pots and grown in a greenhouse. Pots were subjected to an abundant or restricted irrigation regime. Leaf blades and stem internodes were collected from the upper and bottom portion of each hybrid. Tissue samples were incubated in the rumen of 3 rumen-cannulated cows for 0, 3, 6, 12, 24, 48, 96, and 240 hours. Drought stress did not affect the concentration of undigested neutral detergent fibre (uNDF) in upper or bottom internodes but slightly decreased in leaf blades (17.5 and 15.7% for abundant and restricted watering, respectively). The concentration of uNDF varied substantially among corn hybrids in upper internodes (13.4 to 28.3% uNDF), bottom internodes (21.5 to 42.3% uNDF), and blades (11.6 to 20.1% uNDF). Drought stress did not affect the fractional digestion rate (kd) of fibre in any tissue. The kd of fibre varied substantially among corn hybrids in upper (3.8 to 6.6%/h) and bottom internodes (4.2 to 6.7%/h) but did not vary in blades (3.8%/h). Significant interactions existed between irrigation treatment and corn hybrid for the effective ruminal degradation (ERD) of upper and bottom internodes. This interaction did not exist for blades. The ERD of fibre varied substantially among corn hybrids in blades (32.5 to 39.1%). The conclusions of this study are that drought-stressed corn had a marginal increase in fibre digestibility of blades but not in internodes, that drought stress had no effects on ERD of fibre within hybrids, and that the effect of drought stress on fibre digestibility of corn for silage is still inconclusive.

Introduction
Limited and confusing information exists about the impact of drought stress on corn silage digestibility (Soderlund et al., 2012; Ferreira et al., 2020; 2021). In some countries, such as the US, there is a belief among farmers, nutrition consultants, and extension educators that water stress increases the digestibility of the fibre (Mahana and Thomas, 2011; Ferreira, 2020). Because of the difficulties associated with controlling environmental conditions (Farooq et al., 2009), controlled studies comparing the nutritional quality of drought-stressed and non-drought-stressed corn are limited (Ferreira et al., 2021).

Ferreira et al., (2021) reported that drought-stressed corn had a lower in vitro neutral detergent fibre digestibility in corn internodes than non-drought-stressed corn, although that effect did not exist in corn leaf blades. The latter observation suggested that the induced drought might not have been strong enough to exacerbate the effects of drought stress on neutral detergent fibre digestibility. The objective of this study was to determine the effect of irrigation on in situ NDF digestibility (ISNDFD) of corn tissues grown under controlled conditions in a greenhouse.

Materials and Methods
Five commercial corn hybrids (3 conventional and 2 brown midrib) were planted in mini-pots at the Dairy Nutrition Laboratory. After emergence, 6 mini-pots per hybrid were transferred into 6 pots that were later placed in a greenhouse. Pots were subjected to 2 irrigation regimes, which consisted of either 600 or 300 mm of water for abundant (A) and restricted (R) irrigation, respectively.

At harvesting, leaf blades and stem internodes were collected from the upper (UPPER) and bottom (BOTTOM) portion of the plants. Tissue samples were dried at 55°C and ground to pass through a 1-mm screen of a Wiley mill. Ground
samples were inserted into acetone-rinsed porous bags (F57, Ankom Technology, Macedon, NY) and incubated in the rumen of 3 rumen-cannulated cows fed a total mixed ration containing 32% corn silage, 3% alfalfa hay, and 65% concentrate mix (DM basis). Bags were incubated for 0, 3, 6, 12, 24, 48, 96, and 240 hours.

Digestion kinetic parameters were estimated using the NLIN procedure of SAS (SAS version 9.4, SAS Institute Inc., Cary, NC) and according to the model ISNDFD = \( \{ (100 - uNDF) \times [1 - e^{-kd \times T}] \} \), where \( T \) is the time of fermentation in hours, \( uNDF \) is the undigested NDF as a percent of initial NDF after 240 h of fermentation, and \( kd \) is the fractional disappearance rate per hour of the potentially digestible NDF \( (pdNDF) \). The effective ruminal degradability was determined as \( ERD = \{ pdNDF \times \frac{kd}{kd + kp} \} \), where \( kp \) is the passage rate considered at 5%/h.

The experiment was designed and analysed as a randomized complete block design with a 2 \( \times \) 5 factorial arrangement of treatments with 3 replicates. The model included the effects of cow (random; 2 degrees of freedom, df), irrigation treatment (fixed; 1 df), corn hybrid (fixed; 4 df), the irrigation treatment by hybrid interaction (fixed; 4 df), and the random residual error (18 df). Protected multiple comparisons were performed according to the method of Tukey, and significant statistical difference was declared at \( P < 0.05 \).

Results
Due to the limited amount of tissue harvested, we did not analyse data for the BOTTOM leaf blades (Table 1). Drought stress did not affect the concentration of uNDF in UPPER or BOTTOM internodes but slightly decreased it in UPPER leaf blades (17.5 and 15.7% for A and R, respectively). The concentration of uNDF varied substantially among corn hybrids in UPPER internodes (13.4 to 28.3% uNDF), BOTTOM internodes (21.5 to 42.3% uNDF), and UPPER blades (11.6 to 20.1% uNDF). No interactions existed between irrigation treatment and corn hybrid for uNDF concentration. Drought stress did not affect the fractional digestion rate of fibre in any tissue. The fractional digestion rate of fibre varied substantially among corn hybrids in UPPER internodes (3.8 to 6.6%/h) and BOTTOM internodes (4.2 to 6.7%/h) but did not vary in UPPER blades (3.8%/h). No interactions existed between irrigation treatment and corn hybrid for the fractional digestion rate of fibre. Significant interactions existed between irrigation treatment and corn hybrid for the effective ruminal degradation of UPPER and BOTTOM internodes. This interaction did not exist for UPPER blades. The effective ruminal degradation of fibre varied substantially among corn hybrids in UPPER blades (32.5 to 39.1%).

| Table 1: Main effects of in situ ruminal fibre digestion kinetics of 5 corn hybrids grown in a greenhouse at 2 irrigation regimes [600 and 300 mm of water for abundant (A) and restricted (R) irrigation, respectively] |
|------------------|-------------|---|---|---|---|---|---|---|---|
|                 | Irrigation | Hybrid |     |     |     |     | I  | H  | I \( \times \) H |
| **Upper internodes** |            |        |     |     |     |     |     |     |     |
| pdNDF,† % NDF   | 75.7       | 76.9   | 75.7 | 72.6 | 86.6 | 71.7 | 74.7 | 1.5       | 0.31   | 0.01   | 0.76 |
| uNDF,‡ % NDF    | 24.3       | 23.1   | 24.3 | 27.4 | 13.4 | 28.3 | 25.3 | 1.5       | 0.31   | 0.01   | 0.76 |
| kd,§ %/h        | 4.5        | 5.2    | 3.8  | 3.8  | 4.5  | 6.6  | 5.2  | 0.5       | 0.10   | 0.01   | 0.07 |
| ERD,¶ %         | 34.5       | 38.5   | 33.2 | 30.9 | 40.2 | 40.3 | 37.8 | 2.2       | 0.01   | 0.01   | 0.04 |
| **Bottom internodes** |          |        |     |     |     |     |     |     |     |
| pdNDF, % NDF    | 63.9       | 66.0   | 64.7 | 60.4 | 78.5 | 63.4 | 57.7 | 1.6       | 0.23   | 0.01   | 0.42 |
| uNDF, % NDF     | 36.1       | 33.0   | 25.3 | 39.6 | 21.5 | 36.6 | 42.3 | 1.6       | 0.23   | 0.01   | 0.42 |
| kd, %/h         | 5.1        | 5.5    | 4.2  | 5.9  | 4.5  | 6.7  | 5.4  | 0.5       | 0.35   | 0.02   | 0.28 |
| ERD, %          | 31.6       | 33.8   | 29.0 | 32.0 | 36.9 | 35.8 | 29.7 | 1.5       | 0.13   | 0.01   | 0.05 |
| **Upper blades** |            |        |     |     |     |     |     |     |     |
| pdNDF, % NDF    | 82.5       | 84.3   | 79.9 | 82.6 | 88.4 | 80.2 | 85.9 | 1.0       | 0.02   | 0.01   | 0.33 |
| uNDF, % NDF     | 17.5       | 15.7   | 20.1 | 17.4 | 11.6 | 19.8 | 14.1 | 1.0       | 0.02   | 0.01   | 0.33 |
| kd, %/h         | 3.8        | 3.9    | 3.5  | 3.9  | 4.0  | 3.9  | 3.9  | 0.5       | 0.42   | 0.30   | 0.21 |
| ERD, %          | 35.3       | 36.5   | 32.5 | 35.7 | 39.1 | 34.8 | 37.3 | 2.7       | 0.14   | 0.01   | 0.23 |

†pdNDF = potentially digestible neutral detergent fibre.
‡ uNDF = undegraded neutral detergent fibre (after 240 h of fermentation).
§ kd = fractional digestion rate of pdNDF.
¶ ERD = effective ruminal degradation.
**Discussion**

Evaluating the effect of drought stress on fibre digestibility is a difficult task. From one side, it is extremely hard to control environmental conditions to induce and manage drought stress (Farooq *et al.*, 2009). From the other side, growing plants in controlled environments, such as water exclusion shelters or greenhouses, may affect the growing conditions in unusual ways. In this study, for example, we observed very strange looking corn plants with very thin stem internodes, even to the point of needing some assisted support to avoid lodging.

---

**Figure 1:** Effective ruminal degradation of neutral detergent fibre of upper stem internodes from 5 corn hybrids grown in a greenhouse at 2 irrigation regimes (600 and 300 mm of water for abundant and restricted irrigation).

**Figure 2:** Effective ruminal degradation of neutral detergent fibre of bottom stem internodes from 5 corn hybrids grown in a greenhouse at 2 irrigation regimes (600 and 300 mm of water for abundant and restricted irrigation).

In a recent study, Ferreira *et al.*, (2021) concluded that drought stress did not increase neutral detergent fibre digestibility after seeing a marginal decrease in neutral detergent fibre digestibility in drought-stressed corn internodes and claimed that such result is contrary to the belief of the industry. To follow up, this study was designed to better control the growing conditions. Based on the uNDF concentration after 240 h of fermentation, drought stress marginally increased fibre digestibility in upper leaf blades but not in stem internodes. This observation does not agree with that from Ferreira *et al.*, (2021). After analysing the interactions between irrigation and hybrid on effective ruminal degradability (*Figures 1 and 2*), a pattern can be observed indicating that drought stress increased fibre digestion kinetics, although no statistical differences between irrigation treatments were observed within the same hybrid. The observations of the current study agree with those reported by Soderlund *et al.*, (2012), who reported increases of neutral detergent fibre.
digestibility from 50 to 55% with decreasing irrigation. However, different to this study and the previous study (Ferreira et al., 2021), Soderlund et al., (2012) measured fibre digestibility in whole plants, a procedure that may confound structural composition of the plant with fibre digestibility at the tissue level.

From this study we conclude three things. First, drought-stressed corn had a marginal increase in fibre digestibility of leaf blades but not in stem internodes. Second, when comparing irrigation treatments within hybrids, drought stress had no effects on effective ruminal degradation of fibre. Finally, and more broadly, the effect of drought stress on fibre digestibility of corn for silage is still inconclusive and deserves further investigation.

Acknowledgements
This project was partially funded by USDA-NIFA (Multistate Project VA-136291) as part of the multistate project USDA-NIFA NC-2042 Management Systems to Improve the Economic and Environmental Sustainability of Dairy Enterprises. This project also reflects collaborative efforts between Virginia Tech and Egerton University.

References


The effect of water deficits during flowering and seed production on cultivars of subterranean clover and annual medic

Wolfe, E.C (Ted)¹; Collins, W.J.; Rossiter RC³; Stern WR²

¹Graham Centre, Charles Sturt University and NSW Department of Primary Industries, Wagga Wagga NSW 2678, twolfe@csu.edu.au; ²formerly University of Western Australia, Nedlands WA; ³formerly CSIRO, Floreat Park WA

Keywords: drought, annual legumes

Abstract
In improved pastures in inland southern Australia, the persistence and growth of annual pasture legumes depends in part on their ability to produce and conserve abundant seed for regeneration and production. For near-maximum seed production in spring, adequate soil water is needed for at least 70 days in subterranean clover (Trifolium subterraneum) and medic (Medicago) species. Water deficits during spring are a common occurrence, and they appear to be increasing in frequency. The effect of relatively short periods of water deficit during reproductive development has received some attention but the findings conflict. The present experiment was conducted to examine further the responses of subterranean clover to water deficits imposed during the reproductive phase, and to compare the response of medic to that of subterranean clover. The flowering of two early strains of subterranean clover (Northam, Daglish) was synchronised with two early-flowering cultivars of annual medic (Cyprus barrel medic and Harbinger strand medic). Seed production parameters were observed on four watering treatments (nil, early, mid and late deficits during the reproductive phase). Notable differences occurred between the two genera and between the water treatments in their effect on reproductive development. A highly significant interaction favouring medic was recorded between the legumes (clover, medic) and the early deficit treatment, in that the individual seed weight of medic was slightly enhanced by water stress and clover was significantly depressed. In the mid- and late-stress treatments, a significantly lower proportion of viable seed was recorded with clover versus medic. The implications of the findings for the use of adapted annual legumes are discussed.

Introduction
In improved pastures in southern Australia, the persistence and growth of annual legumes, notably subterranean clover and medics, depends in part on their ability to produce and conserve abundant seed (Rossiter 1978) for regeneration and production. For near maximum seed production, adequate soil water is needed from the beginning of flowering for at least 70 days in subterranean clover (Rossiter 1978) and longer in some medic species (Clarkson and Russel 1976). Water deficits are a common occurrence in Australian agriculture. In recent years, the reproductive development of winter-growing annual legumes has been increasingly disrupted by apparent changes to the reliability and predictability of soil water in early spring, a possible manifestation of climate change. In subterranean clover, moderate and severe deficits throughout the reproductive phase depress the rate of flowering (Andrews et al., 1977), shorten its duration (Andrews et al., 1977) and reduce seed production (Andrews et al., 1977, Rossiter 1978). In some species of medic, a significant reduction in the duration of flowering occurs in response to prolonged water stress (Clarkson and Russell 1976), but at the time of the investigation (1980) the comparative reaction of these species to moisture stress during flowering and seed production has not been compared under controlled conditions. The present experiment examined further the responses of subterranean clover to water deficits imposed during the reproductive phase, and compared the response of medic to that of subterranean clover.
Materials and Methods
The experiment was a factorial with four legume cultivars, four water deficit treatments and two replications (= 32 microswards) grown in open-sided glasshouses at CSIRO, Floreat Park. The subterranean clover genotypes were Northam (an early-flowering cultivar with a relatively long duration of flowering) and Daglish (a very early-flowering, early-maturing strain, one of the parents of cv. Nungarin, the earliest maturing subclover cultivar (Gladstones and Collins 1984). The medics were also very early-flowering, Cyprus (a cultivar of barrel medic Medicago truncatula var. truncatula) and Harbinger (a cultivar of strand medic M. littoralis). In May 1980, sieved seeds of each legume (clovers 7.5-7.7 mg, medics 3.0-3.4 mg) were sown at the rate of 25 viable seeds dm\(^{-2}\) (1 dm\(^2\) = 100 cm\(^2\)) into soil in insulated wooden boxes (60 cm x 40 cm x 26 cm deep) on benches. Each box contained 90 kg of a 4/1 sand/loam mixture (bulk density 1.45). Before sowing, commercial fertilisers (g per box) were incorporated into the top 5 cm of soil: Cu-Zn-Mo superphosphate 11.5, potassium chloride 5.8, ammonium nitrate 1.4 and magnesium sulfate 0.35. The sowing dates of these strains were varied to overcome slight differences between these strains in the usual number of days from sowing to flowering (Gladstones and Collins 1984), in a successful attempt to synchronise their start of flowering (mid-August). The boxes were rotated and re-randomized every two weeks. After emergence, the seedlings were thinned to a density of 20 plants dm\(^{-2}\) in early June, and from mid-June to mid-August the microswards were defoliated weekly to a height of 2 cm. During this period, they were watered adequately by a hand-held sprinkler or by filling trays (71 cm x 51 cm x 7.5 cm deep) placed permanently under each box. All of the microswards grew healthily during the vegetative phase. During the reproductive phase, blue-green aphids (Acyrthosiphon kondoi) were controlled by an appropriate insecticide at double the recommended rate. After flowering began in mid-August, the following water management treatments were applied to each strain (note the 21-d wilting period in WE, WM and WL):

- W0 – an unstressed treatment. The water trays were filled late on Sunday, Tuesday and Thursday each week. Excess water was drained away the following morning. Watering ended on 2 November.
- WE – Early stress. Water was withheld from 18 August until 22 September. These microswards began to wilt on 1 September. Until full watering resumed on 22 September, small applications of water (500 mL per box per occasion, total applied 5.0 L per box) were sprinkled on each WE microsward three to four times weekly, to prevent the death of the legumes. Thereafter, as for W0.
- WM – Mid-period stress. Water was withheld from 5 September. Restricted watering (total 5.0 L per box, as above) was applied from wilting (15 September) until 6 October. Thereafter as for W0.
- WL – Late stress. Water withheld from 21 September. Swards began wilting on 30 September. Restricted watering (a total of 6.0 L per box) was applied on four occasions per week during the three-week wilting period until 20 October. Thereafter as for W0.

Measurements
At 0900-1000 hours every Tuesday from pre-flowering until maturity, soil water was determined gravimetrically from cores taken to a depth of 20 cm in each box. The moisture characteristic of the soil was determined using a pressure plate (-0.1 and -0.6 kPa) and pressure membrane (-5 and -15 kPa) equipment. Leaf water stress was measured on green leaflets between 0700 and 0900 hours each Tuesday with an hydraulic press (Campbell Scientific, Model J14). On each occasion, 2-6 leaflets were cut just above the junction of the leaf petiolules, placed between a folded cigarette paper and pressed to an end-point where water clearly exuded from the leaf surface. In late October, leaflet readings on the hydraulic press were calibrated with those made on excised leaves suspended by the petiole in a pressure chamber. Once flowering began, inflorescences within a fixed quadrat (2.25 dm\(^2\)) in each box were counted and tagged three times a week during the first half of the flowering period, and thereafter they were counted before the petals withered. At harvest (early December, after senescence), subterranean clover burrs were removed from a 5 dm\(^2\) quadrat in each box and all medic burrs and tops were collected. These samples were dried for 3-4 days at 40°C and from them were derived values for the total number of burrs produced, the number and individual weight of mature seeds (separated from immature seeds by colour).
and seed yield. Finally, 200 seeds were subsampled from the air-dried seed collected from each box and allocated to petri dishes with moistened filter paper to determine the proportions of seed in four categories: hard seed, soft seed producing normal seedlings, soft seed producing abnormal seedlings and dead seed (that disintegrated in water).

**Results**

**Soil water, leaf water and flowering.** When water was withheld successively from each of the water management treatments (WE, WM, WL), soil moisture fell from 0.16-0.20 cm$^3$.cm$^{-3}$ (field capacity) to reach wilting point (0.04-0.05 cm$^3$.cm$^{-3}$) after 13 d (WE), 9 d (WM) or 7 d (WL). Leaf water readings on the hydraulic press, initially -5 to -8 kPa (equivalent to pressure chamber readings of -5 kPa for both legumes), declined slowly for two weeks and then more rapidly during the next week as the soil dried towards wilting point (-15 kPa), at which point the leaf water deficits were -18 kPa (subterranean clovers) and -22 kPa (medics) on the hydraulic press (equivalent to pressure chamber readings of -15 kPa). Nearing the trough of water status, the leaves began to turn yellow and senesce. At the end of each 21-d period of water deficit, most leaves on the stressed microswards were dead, but restricted surface watering had maintained turgor and a green colour in the stems and some leaves. On the W0 treatment, all of the cultivars reached a peak rate of inflorescence production 14-21 days after all legume cultivars began flowering on 18 August. Northam subterranean clover peaked at 26 inflorescences/week/dm$^3$ compared with Daglish subterranean clover (31), Cyprus medic (53) and Harbinger medic (60). The duration of flowering on W0 (taken when inflorescence production >1/dm$^3$/week) was shortest with Daglish (42 days) compared with Harbinger (63 days) and then Northam and Cyprus (70 days). The cumulative total of inflorescences produced ranged from about 100 per dm$^3$ (Daglish) to >200 (Cyprus and Harbinger). Average inflorescence production was 13 flowers/dm$^3$/day on W0 and WE at 0-7 days after regular watering ceased on WE, 39 (W0) vs 35.5 (WE) at 7-14 d, 38 (W0) vs 27 (WE) at 14-21 d, declining to 19 (W0) vs 1 (WE) at 28-35 d, before the WE treatment was re-watered. Upon re-watering WE, the recovery of vegetative growth and flower production was initially more rapid for the medics than for the clovers; the peak rate of re-flowering was 19, 9, 28 and 23 inflorescences per dm$^2$ per week for Northam, Daglish, Cyprus and Harbinger respectively. The cumulative total number of inflorescences produced on WE was comparable with W0 for the clovers (W0 = 132 per dm$^2$ for Northam, 92 for Daglish), but WE was 25-30% less than W0 for the Cyprus and Harbinger medic. After re-watering the WE treatment, the burrs on the medic microswards continued to swell as they matured. On WM and WL, water stress (indicated by wilting) terminated flowering within 5-7 days. Over the next three weeks, leaf death was considerable but stolons remained green, as did a few leaves. On WM, the flowering rates after re-watering were much lower than on WE after re-watering. On WL, the re-watered microswards failed completely to recover. After watering ended on all treatments (2 November), about 50% of the flowers aborted at maturity on Cyprus medic and 10-20% on Harbinger. Average inflorescence production >1/dm$^3$/week) was shortest with Daglish (42 days) compared with Harbinger (63 days) and then Northam and Cyprus (70 days). The cumulative total of inflorescences produced ranged from about 100 per dm$^3$ (Daglish) to >200 (Cyprus and Harbinger). Average inflorescence production was 13 flowers/dm$^3$/day on W0 and WE at 0-7 days after regular watering ceased on WE, 39 (W0) vs 35.5 (WE) at 7-14 d, 38 (W0) vs 27 (WE) at 14-21 d, declining to 19 (W0) vs 1 (WE) at 28-35 d, before the WE treatment was re-watered. Upon re-watering WE, the recovery of vegetative growth and flower production was initially more rapid for the medics than for the clovers; the peak rate of re-flowering was 19, 9, 28 and 23 inflorescences per dm$^2$ per week for Northam, Daglish, Cyprus and Harbinger respectively. The cumulative total number of inflorescences produced on WE was comparable with W0 for the clovers (W0 = 132 per dm$^2$ for Northam, 92 for Daglish), but WE was 25-30% less than W0 for the Cyprus and Harbinger medic. After re-watering the WE treatment, the burrs on the medic microswards continued to swell as they matured. On WM and WL, water stress (indicated by wilting) terminated flowering within 5-7 days. Over the next three weeks, leaf death was considerable but stolons remained green, as did a few leaves. On WM, the flowering rates after re-watering were much lower than on WE after re-watering. On WL, the re-watered microswards failed completely to recover. After watering ended on all treatments (2 November), about 50% of the flowers aborted at maturity on Cyprus medic and 10-20% on Harbinger. At harvest (early December), the components of seed yield are given in Table 1.

### Table 1: The effect of the water deficit treatments on burr and seed production from microswards of subterranean clover (Northam-N and Daglish-D) and annual medic (Cyprus-C and Harbinger-H).

<table>
<thead>
<tr>
<th>Legume</th>
<th>Water treatment</th>
<th>Burrs.dm$^{-2}$</th>
<th>Seeds.dm$^{-2}$</th>
<th>Seeds/burr</th>
<th>Seed weight</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x</td>
<td>√x</td>
<td>x</td>
<td>√x</td>
<td>#</td>
</tr>
<tr>
<td>Subterranean</td>
<td>W0</td>
<td>106.3</td>
<td>10.31 bc</td>
<td>305</td>
<td>17.47</td>
<td>2.88 c</td>
</tr>
<tr>
<td>clover (Sc)</td>
<td>WE</td>
<td>100.4</td>
<td>10.02 bc</td>
<td>244</td>
<td>15.61</td>
<td>2.43 d</td>
</tr>
<tr>
<td></td>
<td>WM</td>
<td>62.6</td>
<td>7.91 d</td>
<td>125</td>
<td>11.18</td>
<td>1.99 e</td>
</tr>
<tr>
<td></td>
<td>WL</td>
<td>84.6</td>
<td>9.20 c</td>
<td>239</td>
<td>15.45</td>
<td>2.84 c</td>
</tr>
<tr>
<td>Medic (Me)</td>
<td>W0</td>
<td>149.5</td>
<td>12.28 a</td>
<td>642</td>
<td>25.33</td>
<td>4.48 a</td>
</tr>
<tr>
<td></td>
<td>WE</td>
<td>117.3</td>
<td>10.83 b</td>
<td>534</td>
<td>23.10</td>
<td>4.68 a</td>
</tr>
<tr>
<td></td>
<td>WM</td>
<td>68.7</td>
<td>8.29 d</td>
<td>286</td>
<td>16.90</td>
<td>4.24 b</td>
</tr>
<tr>
<td></td>
<td>WL</td>
<td>116.9</td>
<td>10.81 b</td>
<td>471</td>
<td>21.72</td>
<td>4.16 b</td>
</tr>
</tbody>
</table>

**Interactions:** LSD ($P<0.05)$ 0.93 - 0.31 0.28 0.249

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Significance</th>
<th>P&lt;0.05</th>
<th>n.s.</th>
<th>P&lt;0.01</th>
<th>P&lt;0.01</th>
<th>P&lt;0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc v Me x W</td>
<td></td>
<td>P&lt;0.05</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>N vs D x W</td>
<td></td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>C vs H x W</td>
<td></td>
<td>n.s.</td>
<td>n.s.</td>
<td>P&lt;0.01</td>
<td>P&lt;0.01</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>
**Burr and seed production.** On the WE treatment, which began just after the start of flowering (mid-August), the harvested seed yields of the medics were not reduced significantly but clover seed yields were 40% less than the control (W0). The different responses of the clovers and medics to the WE treatment is seen further in the analysis of the seed yield components (Table 1). In summary, the effect of WE on medic was to produce fewer burrs compared with W0, but these burrs contained slightly more seeds (n.s.) that were slightly heavier (n.s.); in contrast, the clover burrs from the WE treatment compared with W0 were lower in terms of all the parameters, significantly so (in most cases). However, when the water stress was applied during the peak of burr and seed development (WM), the seed yields of both the clovers and the medics were reduced considerably compared with W0 (-65% for subterranean clovers and -60% for the medics), while seed production on WL was curtailed only moderately so (-35% for the subterranean clovers, -43% for the medics). The Northam vs Daglish interaction with water, which was of interest due to the better seed production of Northam vs Geraldton at WE in the study of Andrews *et al.*, (1977), was not significant. The Cyprus vs Harbinger medic interaction with water treatment was less important than the main effects of water stress.

**Seed quality.** The data obtained on the quality of the seed produced by each of the clovers and medics revealed another important interaction between clovers and medics (Table 2) in their response to the water treatments. The main differences in seed quality were the higher proportions of dead seed in the WM and WL treatments in the case of the clovers compared with the medics, and a high proportion of abnormal seedlings for the Daglish subterranean clover in these later-imposed water stress treatments.

### Table 2: The effect of the water deficit treatments on the quality of the seed produced from microswards of subterranean clover (Northam and Daglish) and annual medic (Cyprus and Harbinger).

<table>
<thead>
<tr>
<th>Water treatment</th>
<th>Cultivars</th>
<th>Quality of the seed produced on each treatment (%)</th>
<th>Hard seed</th>
<th>Normal seedlings</th>
<th>Abnormal seedlings</th>
<th>Dead seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>No stress</td>
<td>Northam</td>
<td>91.0</td>
<td>7.0</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Daglish</td>
<td>95.0</td>
<td>4.0</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyprus</td>
<td>78.5</td>
<td>15.0</td>
<td>2.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harbinger</td>
<td>78.5</td>
<td>16.5</td>
<td>1.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Early stress</td>
<td>Northam</td>
<td>75.5</td>
<td>17.0</td>
<td>1.5</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Daglish</td>
<td>89.5</td>
<td>6.0</td>
<td>2.0</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyprus</td>
<td>70.0</td>
<td>17.0</td>
<td>5.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harbinger</td>
<td>70.0</td>
<td>22.5</td>
<td>1.5</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Mid-stress</td>
<td>Northam</td>
<td>65.0</td>
<td>10.0</td>
<td>4.5</td>
<td>20.5</td>
<td></td>
</tr>
<tr>
<td>WM</td>
<td>Daglish</td>
<td>34.5</td>
<td>11.5</td>
<td>18.0</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyprus</td>
<td>82.5</td>
<td>12.0</td>
<td>1.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harbinger</td>
<td>87.0</td>
<td>8.5</td>
<td>0.5</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Late stress</td>
<td>Northam</td>
<td>42.5</td>
<td>8.5</td>
<td>9.5</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>WL</td>
<td>Daglish</td>
<td>20.5</td>
<td>36.5</td>
<td>17.5</td>
<td>25.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyprus</td>
<td>92.0</td>
<td>3.0</td>
<td>1.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harbinger</td>
<td>88.0</td>
<td>6.5</td>
<td>1.5</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Cultivar x Water Interaction</td>
<td>LSD (P&lt;0.05)</td>
<td><strong>8.6</strong></td>
<td><strong>6.7</strong></td>
<td><strong>4.3</strong></td>
<td><strong>10.0</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P&lt;0.01</td>
<td>P&lt;0.01</td>
<td>P&lt;0.01</td>
<td>P&lt;0.10</td>
<td></td>
</tr>
</tbody>
</table>
Discussion
The experiment confirmed the serious impact on flowering and seed development of short periods of drought. The effects depended on the timing of these periods in relation to flowering (0-40 days with a peak at about day 20) and seed development (30-70 d, peaking around day 50). The results were notable from three perspectives:

- **First**, there was no significant interaction between the clover strains and the water treatments in terms of seed yield or any of its components. This result contrasted with the investigation of Andrews et al., (1977), who reported that short periods of water stress imposed on the Northam cultivar either early (days 21-46 after first flower) or late (days 32-53 after first flower) had considerably less effect on seed yield than the early and late stresses applied to the Geraldton cultivar, which developed later due to a delay caused by high night temperatures. The Northam/Geraldton water stress treatments were also confounded by a decision to vary the final date of watering of the cultivars. Our results with annual legumes that were synchronised in reproductive development demonstrated similar patterns of seed production of all four strains on the W0, WM and WL treatments, and for both subterranean clover cultivars on WE. Hence, we conclude that the different responses of Northam and Geraldton to short periods of water stress applied by Andrews et al., (1977) were an artefact of their technique.

- The significant clover vs medic interactions in seeds/burr, seed weight and seed yield that occurred in response to the WE treatment comprised the second set of notable results. These interactions collectively featured the ability of annual medics on the early-stressed treatment to compensate for a lower number of burrs by producing slightly more seeds per burr (n.s.) of greater weight (n.s.) compared with significant depressions (P<0.05-0.01) recorded in these parameters for WE subterranean clover.

- The late water stress treatments revealed a third notable finding in the response of the medics and subterranean clovers to water stress, this time in seed quality. Again, the clovers were disadvantaged.

**Overall**, this investigation highlighted the sensitivity of subterranean clover and the superior tolerance mechanisms of Cyprus barrel medic when exposed to short droughts during reproductive development, phenomena that were reported in another study undertaken in 1986 at UWA by S Amoabin (Turner 1990). The lower sensitivity of some legumes to early water stress has been noted also in lentil (Shrestha et al., 2006) and in chickpea (Fang et al., 2011). Fang et al., (2011) reasoned that a recovery of chickpea growth and photosynthesis after re-watering (as in WE) provides a source of carbon for the developing seeds, whereas with terminal drought (as in WM and WL) the later-formed seeds have to compete with early seeds for a diminishing supply of carbon. Since 2000, the range of adapted annual legume species for the Australian wheatbelt has expanded, with the commercialisation and adoption of cultivars of biserrula (*Biserrula pelecinus*), bladder clover (*Trifolium spumosum*), gland clover (*Trifolium glanduliferum*), yellow serradella (*Ornithopus compressus*) and French serradella (*Ornithopus sativus*). These recent pasture legumes have proved successful for several reasons in Western Australia (Loi et al., 2005) and New South Wales (Hackney et al., 2015). Studies of the response of these species to water stress during flowering and seedset may reveal cultivars that, like the medics in this report, have adaptive mechanisms for coping with drought.

**Acknowledgments**
This research was supported by a Reserve Bank Research Fellowship, UWA and CSIRO.
References


The response of selected temperate forages to increasing summer drought conditions and high summer temperatures in northern Victoria, Australia

Rogers, M. E.; Lawson, A. R.; Kelly, K. B.; Wales, W. J. and Jacobs, J. L.

Key words: response of temperate forages, drought, Australia

Abstract
In the dairy region of northern Victoria, Australia, the performance of temperate perennial dairy pastures is often poor over summer due to a combination of high temperatures and limited water availability that can restrict dry matter production and plant survival. A series of field experiments examined the effects of heat and restricted irrigation (as a consequence of drought) on the growth and nutritive characteristics of selected forage species, and whether survival under experimental conditions was influenced by plant genotype, irrigation and grazing management strategies, as well as endophyte presence. The major focus was on perennial ryegrass.

Detailed sampling of perennial ryegrass (Lolium perenne L.), lucerne (Medicago sativa L.) and tall fescue (Festuca arundinacea Schreb) pastures on commercial farms during five extreme heat events (>35°C) over summer 2018/2019, highlighted the impact of high temperatures on pasture nutritive parameters. In vitro dry matter digestibility and water soluble carbohydrate concentrations decreased by 0.2% units per degree rise in average maximum daily temperature from 23 to 40 ºC and neutral detergent fibre and acid detergent fibre concentrations increased by 0.2% and 0.15% units per degree, respectively.

When a range of perennial ryegrass cultivars, hybrid ryegrasses and tall fescue cultivars were evaluated under full and restricted irrigation and two grazing strategies, few differences in net pasture accumulation over summer or survival were observed. The research highlighted the importance of maintaining plant density during periods of restricted irrigation to ensure plant recovery once irrigation or rainfall becomes available. No endophyte-ryegrass combinations were found to be better adapted to restricted water and high temperature conditions.

The incidences of extreme heat events and low water availability are increasing in northern Victoria and this research will assist farmers to identify strategies to mitigate the negative effect of these conditions on the production and feed quality of perennial ryegrass-based pastures.

Introduction
Climate change forecasts for the dairy region of northern Victoria, Australia, predict that mean temperatures will increase by 1.5 to 3°C, and annual rainfall will decrease by 2 and 5% by 2050, leading to greater evapotranspiration and lower volumes of water available for irrigation in this region (Norton et al., 2016). Traditionally, perennial ryegrass (PRG) has been the major component species used in this region, however PRG is better suited to mild, moist conditions (20-25°C) (Cooper and Tainton, 1968) and does not perform well under high summer temperatures (>30°C) (Vough and Marten, 1971, Langworthy et al., 2018,) or when water is limited (Rawnsley et al., 2009, Rogers et al., 2019). Over the past decade, research undertaken by Agriculture Victoria, Tatura, has examined the effects of extreme heat and limited water on PRG growth over summer to determine strategies that optimise pasture production, survival and nutritive characteristics under these conditions. The research has involved quantifying the effect of extreme heat (>35°C for at least three days) on the nutritive characteristics of PRG, lucerne and tall fescue pastures, evaluating a range of PRG genotypes and endophyte combinations for their performance and persistence under conditions of summer drought, and investigating irrigation, grazing and pasture renovation strategies that could be used by farmers over summer.
Materials and Methods

Experiment 1 – Heat effects on nutritive characteristics of perennial ryegrass

During late spring, summer and early autumn of 2018/2019 (November – March), forage was sampled on commercial farms during five extreme heat events to evaluate the effects of high temperatures on the nutritive characteristics. Replicated samples of three forage species (perennial ryegrass, tall fescue and lucerne) were taken before, during, and after, a heat event (maximum temperatures above 35°C). Samples were analysed for in vitro dry matter digestibility (IVDMD), water soluble carbohydrates (WSC), neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP) and important anti-nutritive compounds (alkaloids in perennial ryegrass, and saponins and coumestrols in lucerne).

Experiment 2 – DM production and survival of genotypes following restricted irrigation over summer

The responses of ten cultivars of PRG (Avalon, Banquet II, Base, Bealey, Bronsyn, Extreme, Impact, Impact II, One50 and Prospect), three cultivars of hybrid ryegrass (Barberia, Matrix and Shogun), two cultivars of tall fescue (Quantum and Advance) and their associated endophytes to two irrigation strategies (full season irrigation and restricted irrigation – no irrigation between late December and mid-March) were evaluated over summer for three years (Rogers et al., 2019). The suite of PRG cultivars included a range of Spanish ecotypes that have been reported to have superior summer-drought survival (Matthew et al., 2012). Measurements included net pasture DM accumulation (NPA), plant frequency/sward density and water soluble carbohydrate concentration.

Experiment 3 – Irrigation and grazing management of perennial and short-lived ryegrasses over summer

An on-farm experiment was established at two sites in northern Victoria in March 2015 and ran for three years. At each site, five PRG (Avalon, Base, Bealey, Impact II and One50) and two short-lived ryegrass (SLRG) (Barberia and Crusader) cultivars were sown in two irrigation bays (Rogers et al., 2021). The five cultivars were sown in duplicate, with one of the duplicate PRG, and all of the SLRG plots oversown with the original ryegrass in March 2016 and 2017. One bay was not irrigated over summer (late December to mid-March) and the other bay was irrigated once over this period. In the middle of summer, half of each plot was grazed once. Measurements made included NPA, nutritive characteristics, sward density and botanical composition.

Experiment 4 – Perennial ryegrass and endophyte combinations under limited water.

Fourteen perennial ryegrass / endophyte combinations, comprising five PRG cultivars (Bealey, LP423, One 50, Reward and Trojan) and nine endophytes (nil, SE, AR37, Endo 5, NEA2, NEA3, NEA10, NEA11 and NEA12) were sown in plots in a randomised complete block design at the Agriculture Victoria Tatura Centre. There were two irrigation strategies – full irrigation and restricted summer irrigation (no irrigation from December to March). Measurements made included NPA, endophyte frequency and alkaloid concentrations in tiller bases.

Results

Experiment 1

Severe heat events reduced IVDMD and WSC and increased NDF and ADF concentrations in all species. For all species, both IVDMD and WSC concentrations decreased by 0.2 percentage units while NDF and ADF concentrations increased by 0.2% and 0.15% units, respectively, for each degree rise in three-day maximum temperature. Concentrations of the alkaloid ergovaline in tiller bases were above threshold levels for negative animal welfare outcomes (0.4 mg/kg) on two occasions (14 January – 0.48 mg/kg and 21 January – 0.41 mg/kg) when the three-day maximum temperatures were 40.7ºC and 33.5ºC, respectively. Ergovaline concentrations in the leaf blades were always less than 0.07 mg/kg. Concentrations of coumestrols and saponins in lucerne did not appear to be affected by high temperatures.

Experiment 2

Severe heat events reduced IVDMD and WSC and increased NDF and ADF concentrations in all species. For all species, both IVDMD and WSC concentrations decreased by 0.2 percentage units while NDF and ADF concentrations increased by 0.2% and 0.15% units, respectively, for each degree rise in three-day maximum temperature. Concentrations of the alkaloid ergovaline in tiller bases were above threshold levels for negative animal welfare outcomes (0.4 mg/kg) on two occasions (14 January – 0.48 mg/kg and 21 January – 0.41 mg/kg) when the three-day maximum temperatures were 40.7ºC and 33.5ºC, respectively. Ergovaline concentrations in the leaf blades were always less than 0.07 mg/kg. Concentrations of coumestrols and saponins in lucerne did not appear to be affected by high temperatures.

Experiment 3

Plant frequency declined significantly under restricted irrigation (shown in Figure 1 for Year 1) but there were no differences between PRG cultivars. Annual NPA over the three years was reduced by over 35% (P<0.05) in the restricted compared with the full irrigation treatment (8.5 vs. 12.9 t DM/ha) due to an 85% reduction in summer NPA (0.6 vs 3.7 t DM/ha), a 40% reduction in
NPA in autumn once irrigation recommenced (1.2 vs 2.0 t DM/ha) and a 10% reduction in NPA in winter/spring (6.8 vs 7.5 t DM/ha). There were few differences in NPA among PRG or hybrid ryegrass cultivars (data not presented).

Experiment 3

There were significant variations across sites, seasons, genotypes and irrigation and grazing management strategies. Net pasture DM accumulation from the SLRGs was significantly less than NPA from the PRG (viz. cumulative production of 16.9 t DM/ha vs 19.7 t DM/ha over the duration of the experiment). Measurements of plant frequency indicated large differences between the perennial and short-lived cultivars (viz. 79% plant presence for perennial cultivars compared with 33% for the short-lived cultivars across both sites and years) and some differences between the perennial cultivars (Table 1). In the non-irrigated plots in 2016, plant frequencies were marginally, but significantly, higher in the plots that had been grazed during mid-summer compared with those that had not been grazed (63% vs 60%) whereas, for the irrigated plots, the reverse occurred (75% vs 77%). Summer NPA was very low (range 0.4 to 2.9 t DM/ha) and plots not grazed during summer produced more dry matter in the following cooler period than the grazed plots at least in the first year (viz. 9.22 vs 8.88 t DM/ha).

![Graph showing grass presence as a percentage of cells in either the full (a) or restricted (b) irrigation bays on 30 March 2016. Vertical bars are between cultivar l.s.d. (P=0.05).](image)

Figure 1: Experiment 2. Grass presence as a percentage of cells in either the full (a) or restricted (b) irrigation bays on 30 March 2016. Vertical bars are between cultivar l.s.d. (P=0.05).

Experiment 4

There were no significant differences in NPA between any of the genotype-endophyte combinations in either the full or the restricted irrigation treatments. Similarly, there were no differences in alkaloid concentrations between irrigation treatments or plant genotypes. Peramine concentrations ranged from 0.6 to 12.4 mg/kg DM and ergovaline concentrations ranged from 0.1 to 0.4 mg/kg DM.

Table 1: Experiment 3. The effect of irrigation on plant frequency (% presence) for the three different ryegrass groups in Autumn 2016 and 2017.

<table>
<thead>
<tr>
<th>Cultural group</th>
<th>Autumn 2016</th>
<th>Autumn 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Irrigated</td>
</tr>
<tr>
<td>Short-lived ryegrass</td>
<td>20</td>
<td>39</td>
</tr>
<tr>
<td>Perennial ryegrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>not oversown</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>oversown</td>
<td>65</td>
<td>82</td>
</tr>
<tr>
<td>Chi probability</td>
<td>0.089</td>
<td></td>
</tr>
<tr>
<td>Lsd (P=0.05)</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Within irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between irrigation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion
This series of experiments confirm that PRG is not well suited to the current hot, dry conditions of northern Victoria, let alone the high summer temperatures that are projected to become more extreme and frequent in the future.

Plant nutritive characteristics were significantly reduced by high summer temperatures in all three temperate forage species studied in Experiment 1. In vitro dry matter digestibility has been observed to decline at high temperatures in other studies (for example, Le Gall et al., 2015), corresponding to lower metabolisable energy concentrations, which can then have negative effects on animal performance. The alkaloid ergovaline in the leaf bases in both Experiment 1 and 4 was close to, or above, threshold levels advised for animal health and welfare to prevent disorders such as ryegrass staggers and heat stress (Moate et al., 2012). Any potential effects of ergovaline on the cows grazing these pastures will depend upon the proportion of leaf blade versus tiller bases in the diet, and the proportion of PRG in the overall animal diet.

Net pasture DM accumulation and plant density in PRG decreased under conditions of restricted irrigation in Experiments 2 and 3. The combined stresses of heat and drought are known to be more detrimental to plant growth than either stress alone (Langworthy et al., 2018) suggesting that irrigation may assist temperate plants such as PRG to better survive heat stress by maintaining leaf water status and photosynthesis (Perera et al., 2019). This mitigating effect of irrigation was observed in Experiment 2. However, in Experiment 3, where there were a range of other influences (site, grazing and oversowing), the influence of irrigation management appeared to be more complex. When perennial ryegrass plants are moisture-stressed they are generally more vulnerable to the effects of grazing resulting in fewer surviving plants than when they are ungrazed (Waller et al., 2001).

Perennial ryegrass performed better than the short-lived ryegrasses, particularly in terms of plant density or frequency, however, there were no clear effects of specific PRG genetic background on NPA and survival over summer. The presence of endophyte was not found to provide any benefit in terms of NPA to plants undergoing water stress.

In conclusion, it was difficult to identify any irrigation, grazing management or plant genotype effect that could consistently improve the performance of PRG in the hot, dry summers of northern Victoria, Australia. Dairy farmers may need to explore other options such as alternative, semi-tropical and heat-adapted species, or forage options such as grain and silage to feed their cows over summer in this region.

Acknowledgements
Financial support was provided by Agriculture Victoria, Dairy Australia and Gardiner Foundation. We thank Graeme Phyland, Liz Byrne, Richard Dabrowski and Marg Jenkins for technical assistance and landholders who have allowed us to undertake research on their properties over the past 10 years. The AM Howard Trust provided funding for MR to attend these congresses.

References


Rogers ME, Lawson AR, Kelly KB (2019) Summer production and survival of perennial ryegrass (Lolium perenne) and tall fescue (Festuca arundinacea) genotypes in northern Victoria under differing irrigation management. Crop and Pasture Science, 70: 1163-1174.


Sowing rate effects on biomass production of a forage oat in the Qinghai-Tibetan Plateau

Liu, C.T.; Zhang, H.B.; Deng, J.Q.; Shen, Y.Y.

1State Key Laboratory of Grassland Agro-ecosystems, Lanzhou University
2College of Pastoral Agriculture Science and Technology, Lanzhou University, 730020, China.

Key words: forage oat, sowing rate, stem/leaf ratio, forage yield,

Abstract
Oat (Avena sativa L.) has been a quality forage for the livestock husbandry in the Qinghai-Tibetan Plateau. But farmers tend to use high sowing rates to avoid forage production risks, which does not always give the optimum yield. An field experiment was carried out to explore the response of dry matter production of forage oat Jiayan No.2 to sowing rates in three locations of the Qinghai-Tibetan Plateau: Tianzhu county (TZ), Haiyan county (HB) and Hongyuan county (HY). The five sowing rates were set as 30, 60, 90, 150 and 240 kg·ha⁻¹. Sowing rates had a significant effect on the biomass of forage oat. In TZ, the highest biomass at heading and milking stage was 14.96 t·ha⁻¹ and 22.93 t·ha⁻¹ under 240 and 150 kg·ha⁻¹, respectively. In HB, 15.28 t·ha⁻¹ and 16.75 t·ha⁻¹ biomass yield at heading and milk stage, respectively were observed under 60 kg·ha⁻¹. In HY, the largest biomass yield at two growth stages was up to 3.60 t·ha⁻¹ and 7.49 t·ha⁻¹ under 150 kg·ha⁻¹, respectively. However, sowing rates had no significant effect on the stem/leaf biomass ratio of the plant. Based on the findings of this study, 60 and 150 kg·ha⁻¹ had great significance on achieving high yield and it is recommended for high forage oat biomass production in the Qinghai-Tibetan Plateau.

Introduction
Forage production is the main limiting factor in the livestock production due to the extremely harsh environmental conditions of the Qinghai-Tibetan plateau China, posing a serious threat to the development of local livestock sector (Zhao and Shi., 2004; Fu et al., 2013). Oats is a common annual forage crop with a good productive performance, which can effectively mitigate the situation of forage shortage and promote the development of livestock farming (Xiao et al., 2014). In forage production, sowing rate is one of the important factors that affect forage yield and quality. Due to the genetic characteristics of the varieties and the differences of the production regions, too high and too low sowing rate are not conducive to the growth and development of the forage. Therefore, planting density is of great significance to promote high yield and good quality of forage. The objective of this experiment was to evaluate the responses of DM yield and growth features of a forage oat Jiayan No.2 at three sowing rates in the Qinghai-Tibetan plateau.

Materials and Methods
The experiment was conducted at three locations: Tianzhu county, Gansu province, Haibei county, Qinghai Province and Hongyuan county, Sichuan province, the sites descriptions were shown in table 1.

It was a randomized complete block design with five sowing rates (30, 60, 90, 150 and 240 kg·ha⁻¹) with four replications. Forage oat (Var. Jiayan No.2) seeds were sown by hand at a row space of 20 cm on the 13th May 2019 in 18 m² (3 m × 6 m) plots in each site. The distance between two adjacent plots was one meter. At the heading and milk stage, 1 m length of row was randomly sampled from within the plot away from the edge by cutting. The fresh weight of the stem and leaf were measured after partitioning. All plant samples were oven-dried for about 48 hours at 80- to a constant dryness to determine the dry weight, the stem/leaf ratio and biomass were calculated respectively.
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

Results

Biomass yield

Sowing rates had a significant effect on the biomass production for forage oats in three locations of the Qinghai-Tibetan Plateau. In TZ, under sowing rate of 240 kg·ha\(^{-1}\) at heading stage had biomass yield of up to 14.96 t·ha\(^{-1}\), which was higher than under 30 and 60 kg·ha\(^{-1}\) by 40.6 % and 28.8 % respectively (\(P<0.05\)), but the 150 kg·ha\(^{-1}\) sowing rate at milk stage had biomass yield of up to 22.93 t·ha\(^{-1}\), which was higher than under sowing rate of 30, 60 and 90 kg·ha\(^{-1}\) by 32.0 %, 29.5 % and 26.4 % respectively (\(P<0.05\)). In HB, the biomass yield under sowing rate of 60 kg·ha\(^{-1}\) had the maximum value at both heading and milk stage, up to 15.28 t·ha\(^{-1}\) and 16.75 t·ha\(^{-1}\) which was higher than under sowing rate of 30 kg·ha\(^{-1}\) by 43.9 % and 31.8 % respectively (\(P<0.05\)). In HY, the biomass yield under sowing rate of 150 kg·ha\(^{-1}\) had the maximum value at both heading and milk stage, being 3.60 t·ha\(^{-1}\) and 7.49 t·ha\(^{-1}\), which was higher than under sowing rate of 30 kg·ha\(^{-1}\) by 30.2 % and 37.1 %, respectively (\(P<0.05\)) (Figure 1).

Figure 1: Biomass yield of forage oat under five sowing rates in three locations of the Qinghai-Tibetan Plateau

Note: Different lowercase letters indicates that the indexes of oat at different sowing rates are significantly different at 0.05 level.

Stem/leaf biomass ratio

There was no significant effect of sowing rate on the stem/leaf biomass ratio of the oat in three sites in the Qinghai-Tibetan Plateau (\(P>0.05\)). stem/leaf biomass ratio of forage oat under sowing rate at 60 and 150 kg·ha\(^{-1}\) were up to the maximum at both heading and milk stage in HB and HY respectively, it had for 240 and 150 kg·ha\(^{-1}\) separately had the minimum value at heading and milk stage in TZ (Table 2).

Table 1. Site description

<table>
<thead>
<tr>
<th>Sites</th>
<th>Location</th>
<th>Elevation (m)</th>
<th>Annual temperature (-)</th>
<th>Annual precipitation (mm)</th>
<th>Soil AN (mg/k)</th>
<th>Soil AP (mg/kg)</th>
<th>Soil AK (mg/k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianzhu, Gansu(TZ)</td>
<td>37°09′N-102°51′E</td>
<td>2742</td>
<td>-0.1</td>
<td>416.0</td>
<td>310.2</td>
<td>17.4</td>
<td>104.2</td>
</tr>
<tr>
<td>Haibei, Qinghai(HB)</td>
<td>36°58′N-100°51′E</td>
<td>3156</td>
<td>0.5</td>
<td>369.1</td>
<td>88.0</td>
<td>10.2</td>
<td>168.2</td>
</tr>
<tr>
<td>Hongyuan, Sichuan(HY)</td>
<td>32°47′N-102°34′E</td>
<td>3504</td>
<td>1.1</td>
<td>738.0</td>
<td>450.0</td>
<td>6.8</td>
<td>198.0</td>
</tr>
</tbody>
</table>

Figure 1: Biomass yield of forage oat under five sowing rates in three locations of the Qinghai-Tibetan Plateau

Note: Different lowercase letters indicates that the indexes of oat at different sowing rates are significantly different at 0.05 level.
Table 2: Stem/leaf biomass ratio of forage oat under five sowing rates in three locations of the Qinghai-Tibetan Plateau

<table>
<thead>
<tr>
<th>Sowing rate (kg·ha⁻¹)</th>
<th>TZ</th>
<th>Sites</th>
<th>HB</th>
<th>HY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heading stage</td>
<td>Milk stage</td>
<td>Heading stage</td>
<td>Milk stage</td>
</tr>
<tr>
<td>30</td>
<td>1.37±0.13a</td>
<td>3.70±0.23a</td>
<td>1.67±0.27a</td>
<td>3.56±0.34a</td>
</tr>
<tr>
<td>60</td>
<td>1.52±0.07a</td>
<td>3.94±0.27a</td>
<td>1.84±0.12a</td>
<td>3.81±0.23a</td>
</tr>
<tr>
<td>90</td>
<td>1.39±0.16a</td>
<td>3.55±0.11a</td>
<td>1.57±0.49a</td>
<td>3.68±0.09a</td>
</tr>
<tr>
<td>150</td>
<td>1.51±0.04a</td>
<td>3.39±0.07a</td>
<td>1.34±0.56a</td>
<td>3.59±0.21a</td>
</tr>
<tr>
<td>240</td>
<td>1.37±0.03a</td>
<td>3.74±0.12a</td>
<td>1.33±0.13a</td>
<td>3.57±0.26a</td>
</tr>
</tbody>
</table>

Note: There are significant differences in different lowercase letters in the same column at the 0.05 level.

Discussion

Sowing rate is an important factor to ensure high yield and quality of forage, in global wide, the DM production of oat increased 14 % with the increasing of sowing rate, the greatest DM yield was not always achieved with the increase of sowing rate. These results are similar to what was reported in a previous study (Jing et al., 2019). The low yield at the low sowing rate could be attributed to fewer seeds being sown, while poor light transmittance of the sward may limit tillering by the plants which could prevent achieving high yield at the high sowing rate. Therefore, adopting reasonable planting density can promote the growth of plants and increase the number of effective plants to achieve high yield of forage. In addition, this study also showed obvious regional effects, with biomass of forage oat having different optimum sowing rates in different regionals, and the biomass of TZ and HB was significantly higher than that of HY. This may be caused by the elevation of HY is the highest and rainfall pattern is more variable in the year, which had an negative effects on the biomass production of oat. The region of high altitude may need high sowing rate to reproduce forage oat production.

Stem/Leaf biomass ratio is one of the indexes to measure the quality of forage, where higher leaf can improve the quality of forage and improve the palatability (Gong et al., 2019). This study showed that the sowing rate had no significant effect on the stem/leaf biomass ratio of forage oat Jiayan No.2, which is consistent with previous research (Lin et al., 2019). Therefore, sowing rate had little effect on quality in this study.

Sowing rate had a significant effect on the biomass yield of forage oat in the Qinghai-Tibetan Plateau, while different sowing rates had no significant effect on the stem/leaf biomass ratio. Therefore, through comprehensive analysis we recommend that sowing rate of 60 kg·ha⁻¹ in Heibei, Qinghai province, 150 kg·ha⁻¹ both in Tianzhu ,Gansu province and Hongyuan, Sichuan province for forage production of forage oat Jiayan No.2 to promote the sustainable livestock pastoral system in the Qinghai-Tibetan Plateau.

Acknowledgements for forage production

This work was funded by China Agricultural Research System (CARS-34).

References


Irrigation management strategies for fodder beet \((Beta vulgaris\ L.)\) crops

Khaembah, E. N.; de Ruiter, J. M.; Chakwizira, E.; Maley, S. and George, M.J.

The New Zealand Institute for Plant and Food Research Limited, Private Bag 4704, Christchurch, 8140, New Zealand

Key words: fodder beet, dry matter yield, irrigation, water use efficiency

Abstract
The production of fodder beet \((Beta vulgaris\ L.)\) in New Zealand is concentrated in the South Island, and often requires irrigation to achieve high yields. Development of efficient irrigation management strategies requires information on the effect of timing and rate of irrigation on crop growth. A field study was conducted on a moderately deep soil at Chertsey, Canterbury, New Zealand, to evaluate crop growth responses to five irrigation managements: Rain-fed (control), weekly replacement of full evapotranspiration (FullET-weekly), and 50% of evapotranspiration replaced weekly (HalfET-weekly), fortnightly (HalfET-2weekly) or 3-weekly (HalfET-3weekly). Irrigation to replace ET was adjusted to account for rainfall received between irrigation events. The crop was sown on 11 October 2015. Dry matter (DM) and green leaf area index (LAI) were quantified at 4-weekly intervals from 21 December 2015 until 16 May 2016. Water use efficiency (WUE) was calculated from weekly time domain reflectometry and neutron probe measurements of volumetric soil water content (to 0.8 m depth) and crop biomass. Final yield was lowest for Rain-fed (17.1 t DM/ha) and highest for FullET-weekly (28.9 t DM/ha) treatments. The remaining treatments did not differ in yield, producing 22.4±1.6 t DM/ha, but differed significantly from the Rain-fed and FullET-weekly treatments. Yield differences were associated with the rate of leaf area expansion and duration of critical LAI values \((≥ 3.0 \text{ m}^2/\text{m}^2)\), which were greater for FullET-weekly than for other treatments. Rain-fed and FullET-weekly treatments resulted in the highest and lowest WUE (81 versus 47 kg DM/ha/mm). The remaining treatments did not differ in WUE, averaging 67±3.6 kg DM/ha/mm. Our results show yield benefits from irrigation, with the best outcome from FullET-weekly given the soil type and weather conditions. However, under water restriction conditions, the HalfET-3weekly management is recommended over more frequent partial ET replacements because it would reduce irrigation costs without penalising yield.

Introduction
In New Zealand, fodder beet \((Beta vulgaris\ L.)\) is mainly grown in the South Island, and often requires irrigation to achieve high crop yields (Chakwizira et al., 2014; Khaembah et al., 2019). Globally, demand for food and other amenities from the growing human population is continually exerting pressure on water resources (Boretti and Rosa 2019; Reints et al., 2020). Many countries have policies in place e.g. New Zealand’s National Policy Statement for Fresh Water Management (Freshwater 2017) which require crop production to comply with strict environmental limits associated with water quality and extraction volume from aquifer sources. Therefore, it is important to evaluate the impact of water availability on crop growth to provide insight into irrigation management strategies that conserve water resources while maximising crop yields.

A previous study demonstrated that fodder beet crops growing on deep soils in the South Island produced the same yield when irrigation was applied every 3 weeks to replace 50% of evapotranspiration (ET) compared with more frequent weekly application to replace full ET (Chakwizira et al., 2014). A large proportion of fodder beet growing areas in the South Island are characterised by moderately deep well drained soils that may interact differently with irrigation and affect crop yields. Therefore, the objectives of this study were to evaluate the effect of water...
availability on water use and yield of fodder beet, and define irrigation management options that offer high water use efficiency on a moderately deep soil type.

**Materials and Methods**

The experiment was located at Chertsey, Canterbury, in New Zealand (43°47'30.1"S 171°57'31.4"E) on a moderately deep (~0.60 m), well drained Chertsey silt loam with an available water-holding capacity of ~120 mm/m of depth (Hayman 1985; Chynoweth et al., 2012). ‘Rivage’ fodder beet seed was conventionally drilled with an air seeder at 100,000 seeds/ha on 11 October 2015, to establish ≥80,000 plants/ha. The experiment was a randomized block design with four replications. Five treatments were evaluated: Rain-fed (control); weekly replacement of full evapotranspiration (FullET-weekly); and 50% of evapotranspiration replaced weekly (HalfET-weekly); fortnightly (HalfET-2weekly); or 3-weekly (HalfET-3weekly). The amount of irrigation water applied was calculated from daily ET records obtained from an on-site weather station (NIWA 2020) and adjusted for rainfall.

Volumetric soil water content was measured in 20-cm increments using Time Domain Reflectometers (Model CS616, Campbell Scientific Inc., USA) and Neutron probes (NP) installed at 0–0.2 m and 0.2–0.8 m, respectively. Reflectometers were connected to a data logger (Campbell CR10X) which recorded volumetric soil water content hourly. Measurements began on 26 November 2015 and were completed at the final harvest. Apparent crop water use (WU) was calculated from the change in volumetric soil water content between the sampling day and the start of the experiment, as previously described Chakwizira et al., (2014). Drainage was assumed to be negligible. Water use efficiency (WUE) was calculated as the slope of linear regression of the sequential crop biomass measurements against the WU.

Dry matter (DM) harvests were taken from 2-m² quadrats (2 plant rows x 2 metres of row length) at 4-weekly intervals starting from 21 December 2015 with the final harvest completed on 16 May 2016. At each harvest, plant number and fresh weight were recorded. Sub-samples of two plants from each sample were reweighed and then separated into leaf lamina, petiole and storage root. Laminae were individually scanned through a leaf area meter (LI-COR model LI-3100; Lincoln, NE, USA) to determine leaf area index (LAI). The sub-sample fractions were then oven-dried at 60°C until constant weight to determine dry weight.

Analysis of variance was carried out using GenStat (version 17.1, VSN International Ltd, UK). Significant effects were separated by the least significant difference (LSD) at 5% level.

**Results**

There were yield differences among treatments, observed in late crop development (Fig. 1a). The HalfET-weekly, HalfET-2weekly, HalfET-3weekly treatment crops produced comparable yields (p=0.30) which averaged 22.4±1.1 t DM/ha. Rain-fed and FullET-weekly treatment crops produced the lowest and highest yields (17.1±0.8 and 28.9±0.7 t DM/ha, respectively), both of which differed significantly (p <0.01) from the HalfET treatment crops.

Leaf area development was influenced by irrigation treatment, with FullET-weekly treatments achieving greater LAI than crops under other treatments (Fig. 1b). Maximum LAI was achieved earlier (second sampling) in FullET-weekly crops than those under the rest of the treatments, for which LAI peaked at the third harvest (Fig. 1b). Additionally, FullET-weekly crops maintained critical LAI within the 3–4 range (i.e. critical LAI required for optimal radiation interception and storage root development) for longer than crops under other treatments (Fig. 1b). The LAI in Rain-fed crops was below critical thresholds for most of the season (Fig. 1b).

The total WU for rain-fed crops was 211 mm and increased to 332, 346, 343 and 553 mm in HalfET-3weekly, HalfET-2weekly, HalfET-weekly and FullET-weekly treatments, respectively. Yield correlated positively with WU (R²=0.95). Water use efficiency differed among treatments (p<0.001) and was highest in rain-fed and lowest FullET-weekly crops (81 versus 47 kg DM/ha/mm). Crops under HalfET-weekly, HalfET-2weekly, HalfET-3weekly treatments had comparable (p=0.40) WUE (averaging 67±1.3 kg DM/ha/mm), and these differed significantly from values for crops under both FullET-weekly and rain-fed treatments (p<0.03).
Figure 1: Total dry matter (a) and leaf area index (b) for fodder beet crops grown under different amounts and frequency of irrigation at Chertsey, New Zealand during the 2015-16 growing season. FullET-weekly = full evapotranspiration [ET] replacement per week, HalfET-weekly = 50% ET replacement weekly, HalfET-2weekly = 50% ET replacement fortnightly, HalfET-3weekly = 50% ET replacement every three weeks, Rain-fed = nil irrigation. The shaded region represents critical leaf area index range (3–4). Bars represent the least significant difference at 5% (LSD<sub>0.05</sub>).

Discussion
Yield of fodder beet crops was enhanced by irrigation, with the greatest benefits from full irrigation and lowest yields from rain-fed crops. The HalfET treatments produced the same yield, and differed marginally in the amount of irrigation water applied, indicating that volume of water supplied to crops was more important than frequency of application. On deep soils, Chakwizira et al., (2014) also reported yield benefits from irrigating fodder beet crops, but FullET-weekly crops yielded the same as HalfET-3weekly crops. Such differences in response to irrigation may be attributed to higher water holding capacity of the soil (~190 mm/m of depth) used in the Chakwizira et al., (2014) trial than the ~120 mm/m of depth for the soil in the current trial. Also, there was a difference in the distribution of rainfall during the season, with our experimental site receiving 105 mm less rainfall, which was more sporadic, than that in the Chakwizira et al., (2014) study. As a result, crops in our study were subjected to frequent or longer periods of water deficits which negatively affected the yield of HalfET-3weekly crops. This finding suggests that irrigation management may differ depending on soil type, and amount and distribution of rainfall during the crop season.

Irrigation affected fodder beet yield via canopy development as demonstrated by a greater decline of LAI in rain-fed than in irrigated crops. Studies have shown that LAI determines the capacity of the crop to intercept solar radiation, which ultimately determines yield (Martin 1986; Jaggard et al., 2009). For fodder beet, research has shown LAI of 3–4 (critical LAI) is required to maximize radiation interception (Matthew et al., 2011; Chakwizira et al., 2014). In our study, FullET-weekly crops reached critical LAI values in mid-January when solar radiation was near its seasonal peak, and maintained these values through to early autumn. In contrast, water stress in rain-fed crops slowed canopy expansion and there was accelerated leaf senescence, indicated by a sharp decline in LAI. Consequently, LAI in rain-fed crops was restricted to values below 3 for most of the season. Thus, the high and low yields of FullET-weekly and Rain-fed crops can be attributed to optimal and sub-optimal radiation capture, respectively.

Fodder beet yield increased with WU and decreased with higher apparent WUE, similar to previous findings in fodder beet and other crops (Jacobs et al., 2004; Fletcher et al., 2010; Chakwizira et al., 2014). The apparent inverse correlation of WUE with yield needs to be considered in a wider context of the system, considering other factors such as feed quality and economics. However, the negligible differences in yield and WUE in HalfET crops indicates that under water restriction conditions, the HalfET-3weekly management shows promise over more frequent HalfET-weekly or HalfET-2weekly because it would save irrigator running costs without penalising crop yield. Where water
restrictions are absent, eliminating water stress is recommended.

Irrigation alleviated water deficit and increased fodder beet yield. The fully irrigated crops produced the highest yield, which was associated with early achievement and maintenance of critical LAI for most of the season. The HalfET crops produced the same yield, which was intermediate between those of FullET-weekly and Rain-fed crops. Rain-fed crops experienced water stress which restricted LAI development and reduced yield. Fodder beet yield correlated positively with WU and negatively with WUE. Under the conditions of this study, full irrigation minimized cumulative effects of soil water deficit and maximized yield.

Acknowledgements
Funding for this experiment was provided by the New Zealand Foundation for Arable Research (FAR). We thank FAR and Plant & Food Research technical staff for managing the trial and collecting data.

References


Climate database-NIWA. http://cliflo.niwa.co.nz/ [Accessed 20/05/2020].

THEME3: LIVESTOCK PRODUCTION SYSTEMS

Topic: Challenges on Livestock Production and Rangelands/Grasslands Utilization in Southern South America
Sustainable intensification in crop-livestock systems

Rovira, P\textsuperscript{1}; Carvalho, P.C.F\textsuperscript{2}; Terra, J\textsuperscript{1}; Lattanzi, F\textsuperscript{1}; Pizzio, R\textsuperscript{3}; Ayala, W.\textsuperscript{1}

\textsuperscript{1} Instituto Nacional de Investigación Agropecuaria (INIA, Uruguay); \textsuperscript{2}Universidade Federal do Rio Grande do Sul (UFRGS, Brasil); \textsuperscript{3}Instituto Nacional de Tecnología Agropecuaria (INTA, Argentina).

Key words: pasture-crops; grasslands; biome; beef cattle

Abstract

Extensive livestock production is the main animal source food system in the Pampas and Campos sub-regions in South America. Beef cattle and sheep convert forage biomass that humans cannot eat into nutrient-dense human-edible foods (meat and milk) and valuable co-products (wool). However, diverse global pressures are acting on Pampas systems including increasing demand for protein sources (food security), climate change, environmental footprint, and competition for land. The integration of small areas of pasture-crop rotations is an alternative for increasing efficiency and sustainable intensification of agroecosystems based on natural grasslands. Rotations led by improved pastures increase the carrying capacity and productivity of traditional Pampas systems, and include crop production (soybean, rice) as an opportunity for farm diversification and resilience. Therefore, mixed crop-livestock systems can feed more people in terms of calories and protein than what is possible with specialized systems. The higher carrying capacity in the area under the rotation may allow less intensive grazing management in larger areas of native grasslands reducing threats to biodiversity. Some of the integrated management practices in crop-livestock systems are perennial pastures to mitigate soil organic carbon losses during cropping, biological nitrogen fixation by legumes, grazing cover crops, crop residue grazing, dual-purpose crops, and harvesting grain and hay for livestock feed. Also, complementary crop and livestock production systems facilitate more efficient nutrient cycling and self-sufficient systems promoting the circular economy concept as a strategic approach toward system sustainability. Key to understanding the potential of mixed crop-livestock systems are productive, environmental, economic, and social factors that determine their performance, as well as trade-offs among them. Development, implementation, maintenance, and analysis of long-term crop-livestock platforms research provides science-based information to address complex biological systems, and to implement innovative public policies at national scale to regulate soil use and to prevent non-sustainable agricultural practices.

Introduction

The Pampas and Campo region comprises parts of Argentina and Brazil and the whole of Uruguay (Modernel et al., 2016). It has different subregions defined by vegetation communities, soils, and landscape characteristics (Baldi and Paruelo 2008). The expansion of the agricultural area under continuous cropping and livestock overgrazing of native grasslands are two of the main concerns compromising the sustainability of the Pampa and Campos biome (Medan et al., 2011; Oliveira et al., 2017; Tiscornia et al., 2019). Cultivation of soybean was the most important reason for land use change in the XXI century causing a decline in the area available for livestock. However, cattle numbers remained relatively stable indicating that cattle stocking rates increased in native grasslands areas and decreased in areas dominated by crop production (Modernel et al., 2016). Recoupling livestock and cropping pathways into integrated crop-livestock systems (ICLS) provides an opportunity to achieve sustainable intensification and protect grasslands from conversion to permanent cropland (Smart et al., in press) or overgrazed areas. The objective of this short paper is to review key results of the ‘Palo a Pique’ long term experiment and to discuss the synergy between ICLS and native grasslands in enhancing the sustainability in the Pampa and Campos biome in South America.

Materials and Methods

Data shown in the present paper corresponds to a long-term crop-livestock experiment
established in 1995 in Treinta y Tres (Uruguay) at the National Institute of Agricultural Research (INIA) ‘Palo a Pique’ research unit (33°15’54.4”S 54°29’28.1”W). The dominant soils are Typic Argiudolls with low to moderate soil fertility (1.5 to 2.0% soil organic carbon content (SOC), mass base, in 20 cm depth), occupying a landscape of gently sloping hills where the erosion risk is moderate to high (Terra et al., 2002). The experiment evaluates four different soil use intensities (rotations) with different combinations of pastures and crops under no-till technology (Terra et al., 2006; Rovira et al., 2020). The rotations are: (i) continuous cropping without pastures (CC), (ii) short rotation (SR, two years crops and two years of red clover-based pastures), (iii) long rotation (LR, two years crops and four years of white clover-based pastures), (iv) permanent improved white clover-based pasture (PP) without crops. Each phase of the rotations was represented by a paddock of 6 ha, which was the experimental unit (EU), totaling 12 EUs. Although all phases of the rotations were present at the same time, there were no synchronic replications of each phase. Pastures and forage crops are subjected to direct grazing by growing and finishing Aberdeen Angus cattle.

Results

After 20 years of running the experiment (1995-2015), no soil organic carbon (SOC) differences were found between rotations that included pastures (SR and LR), but they had 21% greater SOC than CC. In addition, SR and LR had lower SOC than PP, while a SOC decreasing trend of 12% was observed in PP compared to the original undisturbed soil under native grasslands located next to the experimental site (Terra and Macedo, 2015). No differences were found in crop yield between the different crop–livestock rotations, averaging (± s.d.) 2499 ± 888, 4871 ± 1758, 2771 ± 1158, and 1569 ± 479 kg/ha for soybean, sorghum, wheat, and oat, respectively, across rotations in the period 2005-2016.

From the animal production standpoint, average liveweight gains (± s.d.) for the first four years of the experiment were 484±151 (CC), 527±61 (SR), 484±82 (LR), and 338±103 (PP) kg/ha per year. In the same period, average forage production was 8.5, 10.2, 9.1, and 7.9 t DM/ha per year for CC, SR, LR and PP, respectively, allowing an animal carrying capacity of 951, 726, 722, and 480 kg LW/ha/year for CC, SR, LR, and PP, respectively (Terra and García-Préchac, 2001). During similar period (1992-2004) and in the same research unit, forage production of native grasslands averaged 3.4 t DM/ha per year, with a seasonal distribution of 35%, 26%, 11%, and 28% in summer, autumn, winter, and spring, respectively (Bermudez y Ayala, 2005). The annual production of the year with the highest production (2002) was three times greater than the production of the year with the lowest production (2004) (5.2 and 1.2 t DM/ha, respectively). For an average year, livestock production in native grasslands ranged between 118 and 145 kg LW/ha/year at a stocking rate between 300 and 420 kg LW/ha (Ayala and Bermudez, 2005).

Discussion

In the Pampas and Campos region the area occupied by grasslands has been reduced by the expansion of soybean. When crops are introduced, rotation with pastures is one of the most basic principles to achieve a sustainable farming system. Here, we describe a large-scale, long-term experiment evaluating four different pasture-crop rotations integrated to livestock production. After 20 years of the experiment, results showed a significant SOC reduction under no-till CC relative to the other rotations containing high proportion of perennial pastures in their cycles. Terra et al. (2006) suggested that the higher content of SOC in pasture-based rotations was related to the greater biomass partitioned to the root systems compared to CC. Recently, evaluating the four rotations using sophisticated models suggested that perennial pastures underpin soil C and nitrogen (N) cycling in crop rotations by maintaining soil C closer to saturation (Pravia et al., 2019). Similar results were obtained in Argentina, where a minimum of 3 years of pastures maintained soil properties within acceptable limits and meet the goals of sustainable intensification in pasture-crop rotations (Studdert et al., 1997).

One of the main features of the experiment is that all paddocks were subjected to direct grazing by beef cattle in a rotationally grazing system adjusting the stocking to pasture conditions. The stocking rate and intensity of grazing determines the amount of residual biomass which is a key parameter for the sustainability of the system. Residual biomass after grazing not only influence animal performance but also represents a physical barrier to compaction through animal trampling, influencing soil aggregation and water dynamics, while avoiding runoff and soil losses from erosion (Carvalho et al. 2018). In Argentina, Fernández et al. (2011) found that the inclusion of livestock to graze cover crops and perennial pastures in ICLS
did not produce deterioration of soil physical conditions; although soil penetration resistance was slightly increased within the first 7.5 cm. However, shallow compaction of the topsoil may develop after years of no-till seeding, even in the absence of grazing (Lavado and Taboada, 2009).

Pastures in ICLS increased 2.5 times the forage production and doubled the animal carrying capacity compared to native grasslands. As a result, LW production in pasture-crop rotations more than tripled compared to LW production in native grasslands. Production intensification is one way to reduce carbon footprint per animal and per hectare (Kanter et al., 2016). In Uruguay, Picasso et al. (2014) found that for every 10 kg increase in productivity (kg LW/ha/year), carbon footprint decreases by 1.2 kg CO2e/kg LW and 36 kg CO2e/ha. Increasing productivity can lower environmental impacts by spreading baseline emissions in higher animal outputs and by reducing the cattle age at slaughter, which also produces more food on less land area (Sánchez Zubieta et al., 2021). In addition to increase LW production, ICLS provide product and economic diversification though grain harvesting during the cropping phase of the rotations which can be sold or used to feed the animals within the system.

Native grasslands are key partners of ICLS. Coupling strategic and small areas of pasture-crop rotations with larger areas of grasslands increases farm sustainability by reducing the risk of conversion to continuous agriculture (Smart et al., 2020) and overgrazing of grasslands (Lemaire et al., 2015). Temperate pastures composed by grasses (i.e. tall fescue, annual cover crops) and legumes (i.e., lotus, red and white clover) in ICLS supply high-quality forage during winter when production is reduced in grasslands, usually dominated by native C4 species (Modernel et al., 2016). This complementary can alleviate overgrazing of native grasslands usually grazed by animals all year around at a relatively constant stocking rate, although its forage production shows large seasonal variation. On the other hand, livestock can be moved to grasslands when the area under the pasture-crop rotation has limited carrying capacity due to conjunctural (i.e. excessive soil moisture in winter) or structural (i.e. area under fallow or recently seeded in autumn and spring) factors inherent to ICLS. To avoid spread of introduced species from pasture-crop rotations to grasslands areas via cattle feces, it is recommended to have a transient or buffer area where cattle can graze for few days before starting to graze the natural pasture area. The role of native grasslands in ICLS is clearly a topic that merits further research.

In conclusion, strategic areas of pasture-crop rotations integrated to livestock grazing are not the problem but part of the solution to protect vast areas of native grasslands from continuous agriculture and overgrazing. Increasing overall productivity while reducing its environmental footprint and conserving the biodiversity in ICLS represents a great challenge due to specific trade-offs among productive, socioeconomic and environmental goals (Latawiec et al., 2014). This poses a major research challenge in identifying and facilitating sustainable farming systems in the Pampas and Campos region. Research platforms, as the ‘Palo a Pique’ long-term experiment, play a key role to provide scientific data supporting sustainable pathways of intensification.

Acknowledgements
We thank the Instituto Nacional de Investigación Agropecuaria (INIA) from Uruguay for providing funds to carry out the ‘Palo a Pique’ long-term experiment. We also thank all the past and present field workers, technicians and students that participated in the collection and analysis of data derived from the experiment.

References


Carvalho, P.C.F., Peterson, C.A., Nunes, P.A.A., Martins, A.P., de Souza Filho, W., Bertolazi, V.T., Kunrath, T.R.,


Lavado, R.S., M.A. Taboada. 2009. The Argentinean Pampas: A key region with a negative nutrient balance and soil degradation needs better nutrient management and conservation programs to sustain its future viability as a world agroresource. *J. Soil Water Conserv.* 64: 150A-153A.


The importance of Campos ecosystem as a world food producer and as a provider of ecosystem services

Ayala, W.²; Bendersky, D.¹; Paruelo, J.²; Rovira, P.²

¹Instituto Nacional de Tecnología Agropecuaria (INTA, Argentina); **Instituto Nacional de Investigación Agropecuaria (INIA, Uruguay)

Key words: native grasslands, herbage production, variability, sustainable use

Abstract
The Campos ecosystem represent one of the largest grassland areas on the world, with great biodiversity in plants and animals. It contributes to improve world food security, based on ruminant livestock production, providing animal protein to feed more than 160.000.000 people. The research agenda for Campos ecosystem demands attention on the productivity and increasing variability phenomena, overgrazing, biodiversity standards and water contamination among other factors. It provides services including genetic resources, carbon storage, control of soil erosion, nutrient recycling, water production with low nutrient concentration and pest control. Overall, there is available technology to improve long-term livestock productivity and preserve current environmental indicators and improve sustainability, contributing to supply increasing world food demand.

Introduction
More than a decade ago, the IGC-IRC agenda held in Hohhot - China 2008 emphasized some emerging issues associated to global warming, the growing population, quality and welfare food, social stability, alternative energy sources, protection of environment and resources among others. The multifunctional use of grasslands introduced a new perspective from potential opportunities provided by grasslands over the world. By 2050, an increase of 34% in world’s population is expected reaching 9.8 billion people (OCDE/FAO, 2017). Currently, the dilemma still in to meet the increasing food demand, preserving biodiversity and ecosystems services and minimizing negative environmental effects. The Rio de la Plata Grasslands region (750.000 km²) in southern South America is one of the largest areas of temperate rangelands over the world. The Pampas and Campos biomes are being affected by the intensification impacts. Despite that, these grasslands feed 42.1 million heads of cattle and 11.9 million heads of sheep, making a significant contribution to global food security (Socioeconomic Atlas, 2018; MAGP-SENASA, 2019; DIEA, 2020).

Impacts, at ecosystem scale, have been driven mainly by agriculture and forestry expansion during the last two decades. In the southern portion of South America, the area of summer crops (mainly soybean) and “double crops” (wheat-soybean within the same paddock) increased by 62% and 52% respectively (Volante et al., 2015). Most of these changes occurred at the expense of perennial crops (mainly cultivated pastures) and natural habitats. These transformations occurred in 14.2% of the rangelands of the Rio de la Plata (Baeza & Paruelo, 2020). In consequence, livestock production systems are being reoriented to increase their profitability. In extensive systems, feed resources are mainly supported by native grasslands, small improved areas and strategic supplementation. Native grasslands increase productivity if improved management practices are applied at global scale. Intensive systems combine introduced pastures in rotation with crops, use of crops residues, cover crops, hay or silage, mainly for finishing animals. Associated synergies contribute to speed up from calf-cow to finishing processes.

Materials and Methods
The Campos region is situated between 24º S to 35º S, covering approximately 500.000 km² of north east of Argentina, south of Brazil and the whole of Uruguay. This area is extended to
approximately 750,000 km² when transitional areas and the pampas region is included (Soriano, 1991; Pallares et al., 2005). It is one of the largest grazing lands in the world for livestock production. The climate is humid subtropical to temperate, with four defined seasons. Rainfall ranges from 1200 to 1600 mm approximately, with a decreasing gradient in temperature from north to south (Oyarzabal et al., 2019). These grasslands are bordered by deciduous xerophytic forest to the west, and deciduous tropical and subtropical humid forests to the north (Overbeck et al., 2007; Andrade et al., 2018; Oyarzabal et al., 2018). Grasslands co-dominated by C3 and C4 species are the most abundant physiognomic type, combined with shrubs and forests (Boldrini, 1997; Overbeck et al., 2007; Perelman et al., 2001, 2017; Oyarzabal et al., 2018; Lezama et al., 2019). Winter is the period with lowest herbage growth rates (5-10 kg/ha/day of DM), contributing with around 10% of annual biomass produced (Bermúdez & Ayala, 2005, Baeza et al., 2010).

Results

Forage productivity and variability

Biomass productivity is affected by soil conditions, fertility, water accumulation, vegetation types. As a reference, annual productivity of native grasslands in the basaltic is 2.9 ± 0.8, 4.5 ± 1.0, 3.8 ± 1.0 to 8.1 ± 0.5 t DM/ha/yr in shallow, black and two deep soils respectively over 15 years (Berretta, 2005; Rodriguez Palma & Rodríguez, 2017). On the granitic areas in the easter region of Uruguay biomass production reaches 1.4 ± 0.6, 1.1 ± 0.5 and 3.7 ± 1.0 t DM/ha/yr in hill, shallow and rolling areas respectively (Mas et al., 1997; Bermúdez & Ayala, 2005). In general, productivity of native grasslands varies from 2.5 to 5.0 t DM/ha/yr, with extreme values of 1.5 to 6.5 t DM/ha/yr under extreme drought or rainy conditions (Ayala et al., 2011). The variability in herbage production between and within years affect pasture management and animal performance in terms of liveweight gains to reproductive performance of herd in extensive systems, demanding adjustments in stocking rate (Cardozo et. al, 2015), strategic use of improved pastures or supplementary feed (Modernell et al., 2016). For those areas of Uruguay dominated by native grasslands, the PSN was around 760 MJ.ha⁻¹.yr⁻¹ or, in meat equivalents, 77 kg.ha⁻¹.yr⁻¹. This represents a forage-to-meat conversion efficiency of 1.17% (Gutierrez et al., 2020). The control of grazing control, generating adequate sward structures, allows to increase animal productivity, soil quality and water infiltration (Nabinger et al., 2011).

Livestock production

The Campos region supports 11.9 and 42.1 million heads of sheep and cattle respectively (Table 1). The high proportion of sheep stock (55%) is settled in Uruguay and the cattle stock (43%) in Argentina. Meat and wool produced is exported in a high proportion to different countries.

Biodiversity and Ecosystem Services (ES) supply

The region has a population of 3000 vascular plants, 450 grasses and 150 legumes with forage value, 385 species of birds and 90 terrestrial mammals (Berretta, 2001; Bilenca and Miñarro, 2004; Pallares et al., 2005; Boldrini, 2007). The great diversity of species makes it a center of origin of germplasm. From the prospective of herbage production, native grasses and legumes are adapted to intensive and frequent grazing and to variations in climate conditions and the occurrence of extreme phenomena (drought -wet, cold-hot, poor fertility-high fertility).
opportunities for the domestication of native species as well as the use of existing genetic variability for the development of new cultivars of those species of forage value. Local genetic resources provide feed source, ornamental, aromatic, nutraceutic or cultural use. Actions of prospection, characterization and conservation are required (Ayala et al., 2011), especially in areas under risk by the agriculture pressure. Based on biodiversity analysis that integrates species richness (plants, animals) together with soil and water status at paddock scale Blumetto et al., (2019) built an integrity ecosystem index (2017), a tool to evaluate the sustainability of productive systems operating on Campos ecosystem according to economic, social and environmental dimensions. Paruelo et al., (2016) presented a synoptic index on the supply of regulating and supporting ES based on remotely sensed data. The Index was tested to evaluate the level of degradation of grasslands areas (Staiano et al., 2020). State and Transition Models were generated for the main grasslands’ communities and geomorphological regions of Uruguay (Altesor et al., 2019, 2020). The Basaltic Cuesta region, in the North-central part of the country presented the best-preserved grasslands.

**Outputs from Campos region**

The intensification process on livestock production is expected in the next decades based on the increase in world population and food demand, affecting the ecosystem services supply from Campos biome and the conservation status (Paruelo et al., 2016; Modernell et al., 2016; Tiscornia et al., 2019; Baeza & Paruelo, 2018; Texeira et al., 2019; Rivero et al., 2021).

Intensification alternatives to increase meat production and maintain/improve ecosystems services supply must consider the following:

1. Effects on biomass production: productivity, overgrazing, floristic composition
2. Effects on livestock production: growth rate, reproductive processes, feed conversion efficiency
3. Effects on renewable resources: soil health, water requirements and quality
4. Effects on environment: erosion, nutrients cycle, greenhouse gas emissions, carbon stock, climate change
5. Effects on population: lifestyle, heritage, consumer preferences, human health

Series of topics related with intensification are in the research agenda of different institutes and universities on the region Campos. The “Grupo Campos” is an organization (see www.grupo-campos.org) with actors involved in research, teaching and transfer actions to promote sustainable livestock production systems. Regularly, meetings allow to see the focus of these group of institutions.

In table 2 there is a list of research topics presented in Proceedings of Grupo Campos during 2017 and 2019 conferences. The 14% of total reports refers to emerging topics such as nutrients cycle and gas emissions. Clearly, topics like biomass production, pasture management and utilization and plant ecology and physiology represent the main focus of the reports (52%). The design and study of production systems and animal performance account for 25% of the list of reports.

A network of approximately 15 universities, 3 research institutes and 3 extension service units are active in the region.

### Table 2: Number of research communications topics on “Grupo Campos Proceedings” between 2017 and 2019.

<table>
<thead>
<tr>
<th>Year</th>
<th>Genetic resources</th>
<th>Productivity Quality</th>
<th>Management Utilization</th>
<th>Ecology Physiology</th>
<th>Diseases Weeds</th>
<th>Nutrients cycle</th>
<th>Gas emissions</th>
<th>Production systems</th>
<th>Animal performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>-</td>
<td>17</td>
<td>3</td>
<td>10</td>
<td>4</td>
<td>11</td>
<td>1</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>2019</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>14</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Grupo Campos (www.grupo-campos.org)

The biome Campos and Pampas in the south of South America have the potential to play an important role in food security for world human population. There is knowledge available to improve productive inputs, intensifying the pastures-based system based on process technologies. There is a regional network including universities, research institutes and extension services to adapt and develop technologies for future scenarios. At the same time, agriculture and forestry are competing for available grassland scenario for livestock but providing synergies as
sub-products to feed livestock or conditions to reduce negative effects of climate and improve animal performance. This region offers a series of ecosystems services, being necessary mitigate emissions, in a changing climate scenario, but maintaining or improving carbon stock inventory. To improve the feed conversion efficiency is critical in terms of improve resources efficiency and reduce contamination.

References


Using perennial rangeland grasses for bioenergy and cattle grazing

Feldman, S.R.1; Sacido, M.B.2; Jozami, E.2; Castagnani, L.2

1Facultad de Ciencias Agrarias UNR, CIUNR & IICAR; ** Facultad de Ciencias Agrarias UNR

Key words: biofuels, lignocellulosic, Spartina, sustainability

Abstract

Increasing energy demand is an outstanding characteristic of XXI century, and though biofuels are an interesting solution they must fulfill environmental safeguards, mostly biodiversity preservation, low greenhouse gas emissions and no competition for land devoted to food production. Spartina argentinensis Parodi is a C4 grass with high growth rates found in extended areas of inland marshes in Argentina that are marginal for agricultural production, and which can continue growing after severe disturbances, such as fire. Indeed, cattle raisers use fire to manage this plant as newly sprouted leaves, though not high quality forage, have better digestibility and protein figures than mature leaves. Cutting and removing of vegetation do not affect the plant or arthropod diversity of the soil or alter soil carbon. Pellets can be obtained and are suitable for heating homes. Plant biomass can be used for biofuels production, i.e. bioethanol and other products obtained by pyrolysis and electricity production, previous gasification. We also found that newly sprouted leaves can be used for livestock grazing with rest periods between cuts to ensure the continuity of the plant community.

Introduction

The invention of the steam engine and the ongoing development of internal combustion engines started the industrial revolution, and rising use of fossil fuels caused the accumulation of greenhouse gases (GHG). There is strong evidence that this accumulation is responsible for the increasing trend in temperature (IPCC 2014). Therefore, it is essential to transition from fossil fuels to renewable energy, using renewable energy sources such as biofuels. First generation biofuels (i.e. corn bioethanol or soybean biodiesel) are controversial due to competition with food crops and high energy demand during production. Second generation or lignocellulosic materials include perennial grasses (Panicum virgatum, Miscanthus spp., among others) and trees with high growth rates (mainly short rotation coppice, Salix spp. and Populus spp.).

We focused on a perennial C4 grass with high growth rates even in soils marginal for agricultural production, and which does not compete with food production: Spartina argentinensis Parodi (=Sporobolus spartinus (Trin.) P.M. Peterson & Saarela). Spartina rangelands occupy circa 30000 km² and have been extensively studied (Lewis et al., 1990), including their high resilience after disturbances (Feldman et al., 2004; Feldman and Lewis 2005; 2007). Prescribed fire is frequently used in these areas because newly sprouted leaves are tender and have higher digestibility and protein content. But such controlled burns often turn into uncontrolled fires that affect non-target areas, from fences to homes. Using satellite images, Veron et al., (2012) found that up to 2 million hectares of all Argentinean rangelands are burned annually, releasing large amounts of CO₂ into the atmosphere without energy use. Sosa et al., (2019) did not detect changes in the vegetation or in the soil arthropod communities after cutting and removal of biomass from S. argentinensis rangeland. Therefore, we propose that using biomass that grows spontaneously in soils not suitable for agriculture and that sustains extensive cattle raising, is an alternative energy source that should be explored (Hill et al., 2006; Tilman et al., 2009). Our aims were to 1) establish the bioenergy outputs of S. argentinensis, 2) explore how to include animal grazing in S. argentinensis production for biofuel, and 3) compare CO₂ emissions of 1 km of displacement in a vehicle using gasoline vs. S. argentinensis bioethanol.
Materials and Methods
Data were collected in the Pampean region of Argentina (32 ° 5'S; 61 ° 22'W). The area is a plain, with a temperate humid climate, annual mean temperatures of 23.7 °C and 11.8 °C, maximum and minimum respectively; and about 1000 mm average annual rainfall (most of it occurring in the warm season, from September to March). Available standing biomass (DM dry matter: 72 hs at 60°C) was determined in a control area (without previous vegetation removal) and at 26 and 78 days after cutting in 3 50 x 50 cm treatment plots. The percentage of protein (AOAC, 1984), NDF (neutral detergent fibre), ADF (acid detergent fibre), and lignin (Goering and Van Soest, 1963) was determined, and in vitro dry matter digestibility (DMM; Ustarraoz et al., 1997) and metabolizable energy were calculated. Metabolizable energy (ME) was calculated using: ME = 3.61 DMM, and maximum stocking rate (MSR) as the possibility of feeding an animal with a requirement of 18.5 Mcal day⁻¹. The supply of forage for cattle (newly sprouted *S. argentinensis* leaves) was calculated considering metabolizable energy of 50% harvest for cuts at 26 and 78 days, and 30% for the control and 219 days. Data were expressed per hectare (ha: 10000 m²), as usual in forage measurements in Argentina and compared using Anova and Tukey using Infostat (Di Rienzo et al., 2014).

The bioethanol production system was modelled from the biomass of *S. argentinensis* (field and industrial stages) working with the Simapro 8.4 Faculty software (PRé Consultants, 2017), considering as a functional unit the production of bioethanol to move 1 km a Taurus Sedan model vehicle (US EPA, 2000) Flex Fuel Vehicle (FFV). The following biomass harvesting tasks were considered: i) tillage with a disk harrow (20 L diesel ha⁻¹); ii) cutting with a brush cutter (10 L diesel ha⁻¹); iii) rotary bale (10 L diesel ha⁻¹); and iv) transport to an industrial plant (30 km from the field), as well as industrial stages (biorefinery: acid hydrolysis, fermentation, filtration, and transport to fuel station). Global warming potential (GWP, CO₂ equivalent emissions) was calculated according to the methodology established by Recipe (Goedkoop et al., 2103) and compared with gasoline. Data of field stages were our own while industrial ones were according to Jungbluth (2007) and Kumar and Murphy 2012. The ethanol to move a Taurus Sedan model vehicle 1 km was compared with the transport of a gasoline vehicle (Wernet et al., 2016) without considering the assembly of the vehicle and the road (asphalt) construction. GWP was compared considering electric production (1 MWh) considering standard Argentinean electric power plants (Argentinean mix) versus electric generation using syngas obtained through gasification procedure.

Results
Plants had the highest growth rates: 37.56 and 38.46 kg DM ha⁻¹ day⁻¹, 26 and 78 days after cutting and removal, respectively. The percentage of crude protein reached values greater than twice that of control plots during the experimental period (26 and 78 days after cutting), with values close to the recommended protein content for livestock production. Protein values remained above the control during the 7 months of growth, approximately. No changes in cell wall fibres percentage were detected throughout the analysed period, while there was accumulation of ash (Table 1).

<table>
<thead>
<tr>
<th>days after cutting</th>
<th>CP</th>
<th>NDF</th>
<th>ADF</th>
<th>Lignin</th>
<th>Ashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>3.32 a</td>
<td>73.06 a</td>
<td>38.04 a</td>
<td>4.81 b</td>
<td>5.43 a</td>
</tr>
<tr>
<td>26</td>
<td>7.81 c</td>
<td>74.60 a</td>
<td>37.27 a</td>
<td>3.98 a</td>
<td>8.80 b</td>
</tr>
<tr>
<td>78</td>
<td>6.80 b</td>
<td>74.24 a</td>
<td>37.81 a</td>
<td>4.88 b</td>
<td>7.43 b</td>
</tr>
</tbody>
</table>

Means within a column with the same letter are not significantly different

Though in vitro digestibility and ME showed slight differences during the experiment, MSR increased after 26 and 78 days if experiment onset (Table 2) due to higher figures of available forage (aboveground biomass).
Table 2: Aboveground biomass, \textit{in vitro} dry matter digestibility (DMD), and maximum stocking rate (MSR) of \textit{S. argentinensis} plots along the experimental period

<table>
<thead>
<tr>
<th>days after cutting</th>
<th>biomass (DM) kg ha$^{-1}$</th>
<th>DMD (%)</th>
<th>MSR ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>5926 c</td>
<td>59.27 a</td>
<td>0.56 a</td>
</tr>
<tr>
<td>26</td>
<td>976 a</td>
<td>59.87 a</td>
<td>2.19 b</td>
</tr>
<tr>
<td>78</td>
<td>3000 b</td>
<td>59.45 a</td>
<td>2.23 b</td>
</tr>
</tbody>
</table>

Means within a column with the same letter are not significantly different.

The GWP of 1 MWh of the Argentine electricity matrix is 675 kg CO$_2$ eq, determining an emission reduction of 91% for the scenario with use of electricity for industrial processes from the grid (60.4 kg CO$_2$ eq) for gasification and 95.5% with self-supply (29.8 kg CO$_2$ eq).

The GWP of a standard vehicle using fossil fuel is 302 g CO$_2$ eq km$^{-1}$, while using \textit{S. argentinensis} bioethanol, the Simapro software established as 154 g CO$_2$ eq km$^{-1}$, reducing emissions by approximately 50%.

**Conclusions**

Our results show that using \textit{S. argentinensis} as a source of bioenergy implies significant savings in GHG emissions. These are interesting figures because they were obtained in spite of the fact that we considered the worst scenario when we included fuel consumptions during the harvest procedures, as well as thermochemical pre-treatments during bioethanol production. Using ligninolytic enzymes would lower fuel consumption during pre-treatments, therefore lowering GHG emissions.

Biomass removal for bioenergy should be carried out in spring to have a better quality and homogeneous forage supply, which leads to greater harvest efficiency by cattle. After cutting \textit{S. argentinensis} for bioenergy, we recommend rotational grazing of cattle with high instantaneous loads and low occupation time. This grazing should be carried out around 70-80 days post-cutting, since at that time the plants have good CP content, digestibility and accumulated biomass. We still have to establish the optimal grazing intensity and duration of the rest period to ensure that \textit{S. argentinensis} and the entire plant community recover, but current initial results are promising.

Today we face what Tilman \textit{et al.}, (2009) called a “trilema”: food, energy and environmental demand. As food demand increases, using farmland for energy crops is unwise, energy demand continues increasing, and greenhouse gasses emissions are among the highest contaminant concerns due to global climate change. We propose using perennial rangeland species, i.e. \textit{S. argentinensis} for bioenergy and livestock production to contribute towards solving this trilema.

**Acknowledgements**

This research was supported by a grant of the Universidad Nacional de Rosario, Argentina.

**References**


Goedkoop, M., Heijungs, R., Huijbregts, M., Schryver, A., Struijs, J., and Van Zelm, R. 2103. \textit{Quick introduction into ReCiPe LCIA Methodology}.


THEME 5: DROUGHT MANAGEMENT AND CLIMATE IN RANGELANDS/GRASSLANDS

Topic: Climate Change Impacts and Mitigation
Differential effects of changed precipitation patterns on co-existing dominant species in Inner Mongolia typical grassland: significance for drought management

Zhou, S-X\textsuperscript{1}; Wu, D-X\textsuperscript{1}.

\textsuperscript{1}Institute of Botany, Chinese Academy of Sciences, China; \textsuperscript{2}The New Zealand Institute for Plant and Food Research Limited, New Zealand

Key words: changed rainfall regimes; water stress; rainfall interval; rainfall frequency; root

Abstract

More extreme precipitation patterns are occurring worldwide in the context of global climate change. These patterns are characterized by larger event size separated by longer within-season drought periods, which are novel climatic conditions to many ecosystems while their consequences are largely unknown. Consequences of changed precipitation patterns on grassland could be complex since the effects of precipitation interval and total precipitation quantity can interact greatly with each other, and can differ among co-existing dominant species. Meanwhile, few researches explored the impacts of changed precipitation patterns on the hidden half – grassland root system. The objective of this study is to explore the responses of co-existing dominant species (\textit{Leymus chinensis} and \textit{Stipa grandis}) of Inner Mongolia typical grassland to changed precipitation pattern. A simulated experiment over the whole growing season (July to September) was conducted in open-top chambers at Inner Mongolia Grassland Ecosystem Research Station of Chinese Academy of Sciences. The research examined the effects of total precipitation quantity and precipitation interval on their aboveground and belowground growth and root/shoot ratio. It was found that precipitation interval was as significant as total precipitation quantity in affecting growth of the two dominant species. Belowground growth of \textit{Leymus chinensis} and \textit{Stipa grandis} responded to changed precipitation patterns in opposite ways, and the effects of total precipitation quantity and precipitation interval depended greatly on each other. It was inferred that precipitation pattern of relatively higher total precipitation quantity and relatively longer precipitation interval would favour growth of \textit{Leymus chinensis}, and precipitation pattern of relatively lower total precipitation quantity and relatively longer precipitation interval would favour for growth of \textit{Stipa grandis}. These differential results provide important insight for drought management strategies in this area in face of future climate change scenarios.

Introduction

As global climate models have predicted and lots of observing and research evidences have confirmed, besides the increasing precipitation quantities on the global level, more extreme precipitation patterns are occurring together with atmospheric warming. Precipitation patterns are predicted to change world-wide in terms of the total precipitation quantity, the precipitation interval and the precipitation quantity of each event (e.g., Meehl \textit{et al.}, 2005). Water is the main limiting factor of grassland ecosystem, while researchers usually pay more attention to the total precipitation quantity but not the change of precipitation pattern. The distribution of rainfall events in a season is important to the growth of plants, such that the frequency and intensity of rainfall events may be both important for regulating plant productivity (Swemmer \textit{et al.}, 2007). The predicted more extreme precipitation patterns, which are characterized by larger event size separated by longer within-season drought periods, are novel climatic conditions to many ecosystem types while influences are largely unknown.

Due to various limitations, few studies on response of grasslands to changed precipitation patterns had put emphasis on the belowground variables, especially for the belowground growth dynamics within growing season. For instance, studies on impacts of changed precipitation pattern on growth of root system and the ratio of root to shoot biomass allocation are limited (Chou \textit{et al.}, 2008).
This study explored the effects of changed precipitation pattern on the above- and below-ground growth and root/shoot ratio of two co-existing dominant species (*Leymus chinensis* and *Stipa grandis*) of Inner Mongolia typical grassland. The objective of this study is to explore their responses to changed precipitation pattern which can provide important insight into responses of Inner Mongolia typical grassland to future changed precipitation patterns in the context of global climate change.

**Materials and Methods**

A simulated experiment was conducted on seedlings of *Leymus chinensis* and *Stipa grandis* – two dominant species of Inner Mongolia typical grassland – in open-top chambers at Inner Mongolia Grassland Ecosystem Research Station of Chinese Academy of Sciences (Figure 1). The duration of treatments was 75 days, from July 16 to September 30, 2009. The study site and experimental procedures were described in Zhou (2010). In brief, the experimental simulation included two total rainfall levels (Q1: 150mm – the average rainfall quantity of the site during the same period in the past 27 years, and Q2: 50% increase in total rainfall – 225mm), two rainfall interval levels (I1: one event every 5 days, and I2: one event every 15 days) and one natural rainfall level during the experiment (the natural rainfall situation outside the OTC in the experiment). The total rainfall gradient and rainfall pattern can be simulated by controlling the single watering amount and watering interval. The four watering scenarios were: (1) Q1I1, the total rainfall was 150 mm, the rainfall interval was 5 days, and plants were watered with 10 mm each time; (2) Q1I2, the total rainfall was 150 mm, the rainfall interval was 15 days, and plants were watered with 30 mm each time; (3) Q2I1, the total rainfall was 225mm, the rainfall interval was 5 days, and plants were watered with 15 mm each time; (4) Q2I2, the total rainfall was 225 mm, the rainfall interval was 15 days, and plants were watered with 45 mm each time. The effects of total precipitation quantity (Q1 and Q2) and precipitation interval (I1 and I2) on aboveground and belowground growth and root/shoot ratio were examined. Differences were tested using a One-Way ANOVA with a Tukey post hoc test of significance.

**Figure 1:** Distribution of six rainfall-sheltered Open top chambers, and location of seedlings in buckets, whose one half was planted with ten plants from the very beginning and the other half did not, allowing root proliferation to the unplanted half bucket area from plants in the planted half bucket area.

**Results**

At final harvest, aboveground biomass of seedlings of *Leymus chinensis* was increased by an average of 33.9% ($P < 0.05$) by increased total precipitation quantity (+50%) and an average of 31.3% ($P < 0.05$) by extended precipitation interval from 5 days to 15 days (Figure 2). Aboveground biomass of seedlings of *Stipa grandis* was increased by average 23.0% ($P < 0.05$) by increased total precipitation quantity (+50%) and by an average of 48.8% ($P < 0.001$) by extended precipitation interval from 5 days to 15 days (Figure 2).
When compared with that under low total precipitation quantity with same precipitation interval, root biomass and belowground biomass of seedlings of *Leymus chinensis* were respectively increased by 58.3% \((P < 0.05)\) and 62.4% \((P < 0.05)\) by increased quantity with long interval, while they were not significant affected by increased quantity with short interval (Figure 3). When compared with that under short precipitation interval with same total precipitation quantity, root biomass and belowground biomass of seedlings of *Leymus chinensis* were respectively increased by 88.7% \((P < 0.001)\) and 70.6% \((P < 0.05)\) by extended interval with high quantity, while they were not significant affected by extended interval with low quantity (Figure 3). Total precipitation quantity had no significant effect on belowground biomass of seedlings of *Stipa grandis*. When compared with that under short precipitation interval with same quantity, belowground biomass of seedlings of *Stipa grandis* were increased by 56.2% \((P < 0.001)\) by extended interval with low quantity, while were not significant affected by extended interval with high quantity (Figure 3).

**Figure 2**: Dynamics of aboveground biomass of seedlings of *Lymus chinensis* and *Stipa grandis* in different precipitation patterns (mean ± SE, \(n = 5\)). Significant differences at \(P < 0.05\) are indicated by different letters.

**Figure 3**: Dynamics of belowground biomass of seedlings of *Lymus chinensis* and *Stipa grandis* in different precipitation patterns (mean ± SE, \(n = 5\)). Significant differences at \(P < 0.05\) are indicated by different letters.
The effect of total precipitation quantity on root/shoot ratio of seedlings of *Leymus chinensis* depended on precipitation interval. Root/shoot ratio was decreased by 28.5% \((P < 0.05)\) by increased total precipitation quantity only under short precipitation interval level (Figure 4). The effect of total precipitation quantity and precipitation interval on root/shoot ratio of seedlings of *Stipa grandis* depended greatly on each other. Root/shoot ratio was decreased by 28.4% \((P < 0.05)\) by increased total precipitation quantity only under extended precipitation interval level, and decreased by 28.8% \((P < 0.05)\) by extended precipitation interval only under increased precipitation quantity level (Figure 4).

Figure 4: Dynamics of root/shoot ratio of seedlings of *Lymus chinensis* and *Stipa grandis* in different precipitation patterns \(\text{mean} \pm \text{SE}, n = 5\). Significant differences at \(P < 0.05\) are indicated by different letters.

During whole treatment period, the differences of aboveground biomass, belowground biomass and total biomass of seedlings of *Leymus chinensis* between treatments for seedlings treated for 30 days and 45 days were determined by total precipitation quantity, while for seedlings treated for 75 days, differences of belowground biomass were determined by precipitation interval, and differences of aboveground biomass and total biomass were co-determined by total precipitation quantity and precipitation interval. The difference in aboveground biomass, belowground biomass and total biomass of seedlings of *Stipa grandis* between treatments for seedlings treated for 30 days and 45 days were determined by total precipitation quantity, while for seedlings treated for 75 days those biomass differences were determined by precipitation interval.

**Discussion**

It was inferred that precipitation interval could be a key factor as important as total precipitation quantity in affecting growth of seedlings of *Leymus chinensis* and *Stipa grandis* in Inner Mongolia typical grassland. Effects of precipitation pattern on plant growth could be complex since the effect of precipitation interval and total precipitation quantity interacted greatly with each other, and changed with treatment period. Belowground growth of *Leymus chinensis* and *Stipa grandis* responded to changed precipitation patterns in opposite ways while effects of total precipitation quantity and precipitation interval depended greatly on each other. It was predicted that precipitation pattern of relatively high total precipitation quantity and relatively long precipitation interval would do good for growth of *Leymus chinensis*, and precipitation pattern of relatively low total precipitation quantity and relatively long precipitation interval would favour growth of *Stipa grandis*.

The results in this study were based on observations from seedlings of two species for one growing season, which remain to be tested for (1) longer-term responses which could change across seasons and years, (2) species of different climatic origin and/or plant function type (PFT), which could exhibit differential drought sensitivity and acclimation (e.g., Zhou *et al.*, 2016) and (3) responses to co-occurring abiotic and biotic stresses involving changed precipitation pattern. The scaling-up of species-level findings to ecosystem scale would be interesting to understand the response of Inner Mongolia grasslands to changed precipitation patterns more systematically. Changes in plant
community composition related to drought response are already beginning to be reported. For instance, the more drought-tolerant *Quercus pubescens* is replacing *Pinus sylvestris* at low altitudes in Switzerland, where recurrent water deficit has been brought about due to climate change (Eilmann *et al.*, 2006). Model-experiment synthesis effort in this area can enhance our predictions of drought consequences on species distributions and vegetation composition on arid and semi-arid ecosystems, particularly in a long-term perspective that takes future climate change scenarios into account (Zhou *et al.*, 2019). Transparent incorporation of the observation-derived PFT-level variation in drought responses into ecosystem models may be necessary. Prospect drought mitigation and adaptation strategies could incorporate the inter-species variation in drought response, which have important implications for management of water-limited ecosystems such as grassland.

Acknowledgements
This research was supported by National Natural Science Foundation of China (30270945, 31660679, 31770500), the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX2-YW-433-02), and the Innovative Team of Grassland Resources from the Ministry of Education of China (IRT_17R59). We also acknowledge Inner Mongolia Grassland Ecosystem Research Station of Chinese Academy of Sciences, College of Grassland, Resources and Environment, Key Laboratory of Grassland Resources of the Ministry of Education, Key Laboratory of Forage Cultivation, Processing and High Efficient Utilization of the Ministry of Agriculture and Rural Affairs, Inner Mongolia Key Laboratory of Grassland Management and Utilization, Inner Mongolia Agricultural University for their support.

References


Risk of climate-related impacts on global rangelands – a review and modelling study

Godde, C.M.¹, Boone, R.B.², Ash, A.¹, Waha, K.¹, Sloat, L.², Thornton, P.³, Mason-D’Croz¹, D., Mayberry¹, D., Herrero, M.¹

¹Commonwealth Scientific and Industrial Research Organization (CSIRO), St Lucia, Queensland, Australia
²Colorado State University, Fort Collins, Colorado, United States
³CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS), ILRI, Nairobi, Kenya

Key words: livestock; rangeland; grazing; climate change; climate variability

Abstract
Climate change threatens the ability of global rangelands to provide food, support livelihoods and deliver important ecosystems services. The extent and magnitude of potential impacts are however poorly understood. In this study, we review the risk of climate impacts along the rangeland systems food supply chain. We also present results from biophysical modelling simulations and spatial data analyses to identify where and to what extent rangelands may be at climatic risk. Although a quantification of the net impacts of climate change on rangeland production systems is beyond the reach of our current understanding, there is strong evidence that there will be impacts throughout the supply chain, from feed and animal production to processing, storage, transport, retailing and human consumption. Regarding grazing biomass production, this study finds that mean herbaceous biomass is projected to decrease across global rangelands between 2000 and 2050 under RCP 8.5 (-4.7%), while inter- (year-to-year) and intra- (month-to-month) annual variabilities are projected to increase (+21.3% and +8.2%, respectively). These averaged global estimates mask large spatial heterogeneities, with 74% of global rangeland area projected to experience a decline in mean biomass, 64% an increase in inter-annual variability and 54% an increase in intra-annual variability. The potentially most damaging vegetation trends for livestock production (i.e., simultaneous decreases in mean biomass and increases in inter-annual variability) are projected to occur in rangeland communities that are currently the most vulnerable (here, with the lowest livestock productivities and economic development levels and with the highest projected increases in human population densities). Large uncertainties remain as to climate futures and the exposure and responses of the interlinked human and natural systems to climatic changes over time. Consequently, adaptation choices will need to build on robust methods of designing, implementing and evaluating detailed development pathways, and account for a wide range of possible futures.

Introduction
The various contributions of rangelands to the economy, human livelihoods and other ecosystems services highlight the importance of better understanding the potential impacts of climate change on rangeland production systems. In this article, we first review the potential impacts of climate change along the rangeland systems food supply chain (section 2). We then present results from biophysical modelling simulations and spatial data analyses to identify where and to what extent rangelands may be at climatic risk (sections 3 and 4). Further details about the findings are presented in Godde et al., (2020) and Godde et al., (2021). This study is framed around the concept of risk of climate-related impacts, as defined by the Intergovernmental Panel on Climate Change Working Group II (IPCC, 2014). Risk results from the interaction of climate-related hazards with the exposure and vulnerability of human and natural systems. We use the term hazard to refer to climate-related physical events or trends that impact livestock systems (IPCC, 2014). Exposure refers to the parts of the livestock supply chain that could be adversely affected, while vulnerability encompasses humans’ capacity to cope and adapt.
Potential impacts of climate change throughout the value chain

Major climate trends that can impact the livestock food supply chain are increases in atmospheric carbon dioxide (eCO\textsubscript{2}) and tropospheric ozone (O\textsubscript{3}) concentrations; changes in both mean and variability of temperature and precipitation; sea level rise and storm surges; and increased risk and frequency of extreme weather events.

These climate change hazards may adversely affect the different stages of the livestock supply chain, from the availability and quality of resources such as animal feed and water, to the welfare and productivity of animals. For instance, droughts, fires, storms, flooding events, surface melt and icing events can disturb crop growth, reduce arable land and restrict animal access to pastures. Although less documented in the literature, climate change also has implications for human labour and the processing, storage, transport, retailing and consumption of livestock products. For example, higher temperatures, increased humidity, increased frequency of extreme weather events, and rising sea levels are likely to put additional stress on built-up capital such as machineries, transportation infrastructures, electricity networks and telecommunications. Commodity prices are also likely to increase and be more volatile under climate change. Key potential impacts are summarised in Figure 1 and further detailed in Godde et al., (2021).

Rangelands biomass production under climate change – insights from biophysical modelling

To better understand the extent to which climate change may impact on rangelands grazing biomass production, the global rangeland model G-range (Boone et al., 2018) was run under climate change scenarios. Findings are summarised below and further detailed in Godde et al., (2020). Rangelands are at 11 threat from climate change, although the extent and magnitude of the potential impacts are poorly understood. Any declines in vegetation biomass and fluctuations in grazing availability would be of concern for food production and ecosystem integrity and functionality. In this study, we use a global rangeland model in combination with livestock and socioeconomic datasets to identify where and to what extent rangeland 15 systems may be at climatic risk. Overall, mean herbaceous biomass is projected to decrease across global 16 rangelands between 2000 and 2050 under RCP 8.5 (-4.7%). Overall, mean herbaceous biomass is projected to decrease across global rangelands between 2000 and 2050 under Representative Concentration Pathways (RCP) 8.5 (-4.7%), while inter-(year-to-year) and intra-(month-to-month) annual variabilities are projected to increase (+21.3% and +8.2%, respectively – standard deviation divided by mean). These averaged global estimates mask large spatial heterogeneities, with 74% of global rangeland area projected to experience a decline
in mean biomass, 64% an increase in inter-annual variability and 54% an increase in intra-annual variability (Figure 2). Half of global rangeland areas are projected to experience simultaneously a decrease in mean biomass and an increase in inter-annual variability—vegetation trends both potentially harmful for livestock production. These regions include notably the Sahel, Australia, Mongolia, China, Uzbekistan and Turkmenistan and support 376 million people and 174 million ruminant Tropical Livestock Units.

**Figure 2:** Trends in herbaceous dynamics as projected by G-Range by 2050. Panel A shows regional percent changes (data-points weighted by their amount of land devoted to rangelands). Panel B highlights dynamics at the pixel resolution. The sign (+) indicates an increase in the vegetation variable value by 2050 and (-), a decrease. EAS: Eastern Asia, EUR: Europe and Russia, LAM: Latin America and the Caribbean, MNA: the Middle East-North Africa, NAM: North America, OCE: Oceania, SAS: South Asia, SEA: Southeast Asia, SSA: sub-Saharan Africa. Climate scenario: HadGEM2-ES RCP 8.5 with atmospheric CO$_2$ effects enabled. Adapted from Godde et al., (2020).

**Rangelands risk of climate-related impacts – insights from spatial data analyses**

The vulnerability of rangeland communities depends not only on the potential impacts of climate change on the various stages of the supply chain, but also on the ability of these communities to cope with changes. We couple the above-described modelled vegetation trends with spatially-explicit livestock, demographic and economic datasets. We find that the vegetation trends potentially most damaging for livestock production are projected to occur in rangeland communities that are currently the most vulnerable according to the variables considered. These communities have, on average, the lowest livestock productivities and economic development levels and the highest projected human population growth by 2050 (Figure 3, red bars). The greatest rates of decrease in herbaceous biomass by 2050 are also projected to occur in regions with currently the highest stocking rates, lowest livestock productivities and GDP-PPP and highest population growth by 2050 (not shown here).

**Figure 3:** Trends in herbaceous dynamics as projected by G-Range by 2050 and selected current rangeland socio-economic characteristics. The sign (+) indicates an increase in the vegetation variable value by 2050 and (-), a decrease. For instance, on panel D, the areas projected to experience simultaneously a decrease in mean herbaceous biomass and an increase in year-to-year variability (red)
are areas that, in 2010, have on average the lowest GDP-PPP values (see Y-axis value). In contrast, the areas projected to experience simultaneously an increase in mean herbaceous biomass and an increase in inter-annual variability (yellow) have, in 2010, on average the lowest GDP-PPP values (see Y-axis value, panel D). Number of data-points in each boxplot: 1856 (blue), 1221 (yellow), 1659 (orange), 6203 (red). Within each of the five panels, groups that were found to have means statistically significantly different from all other boxes in pairwise comparison do not share the same letter (a-c) (Tukey HSD test, p-value<0.05). Adapted from Godde et al., (2020).

Discussion
Climate-related risks in rangeland systems result from the interaction of climate hazards with the exposure and vulnerability of human and natural systems. Risks will be context specific, but also greatly influenced by global socio-economic trends and shocks. Differences in risks arise from both climatic and non-climatic factors as well as from uneven socio-economic development processes. These context specificities highlight the importance of renewed attention to the diversity of systems and contexts within the livestock sector and its multiple socio-economic and environmental contributions.

While it is certain that climate change will impact rangeland systems throughout the livestock value chain, large uncertainties remain as to the nature, extent and magnitude of these impacts. Uncertainties relate to the future climate as well as exposures and responses of the interlinked human and natural systems to climatic changes over time. Increases in inter-annual variability of forage availability is especially a concern for the grazing sector. The increase in frequency, intensity and duration of heat waves also poses a major threat to animal health and human labour where access to mechanisation and cooling systems is limited. These climate-related hazards can exacerbate other stressors with negative impacts, especially for people living in poverty. The nature and extent of such impacts are however still largely unknown and require further research.

In the face of global warming, the existing suite of adaptation strategies and coping range that have been developed in response to existing weather patterns may not be enough. Barriers to implementation are also significant and may be stronger in areas with low economic development, which this study finds to also potentially experience the most harmful vegetation trends for livestock production. The deepening of our understanding of the climate hazards, exposure and vulnerability of the ecological and socio-economic components of rangelands, is a necessary step to identify successful adaptation pathways in times of climate change and other future uncertainties.

Acknowledgements
This paper constitutes an output of the following projects: Bill and Melinda Gates Foundation LiveGaps (OPP1134229), International fund for Agricultural Development ‘Climate-smart dairy systems in East Africa through improved forages and feeding strategies: Enhancing productivity and adaptive capacity while mitigating greenhouse gas emissions’ (2000001002). P.K.T also acknowledges financial support from the CGIAR Programme on Climate Change Agriculture and Food Security (CCAFS). The views expressed here cannot be taken to reflect the official opinions of these organizations.

References


Visual assessment of soil structure as an early indicator of soil quality in response to intensive rotational grazing

Teutscherova, N1; Vazquez, E2; Baquero, D3; Velasquez-Ruiz, NE4; Pulleman, M5; Arango, J5.

1Czech University of Life Sciences Prague; 2University of Bayreuth; 3Centro de negocios ganaderos, Colombia; 4Never+SAS; 5International Centre for Tropical Agriculture (CIAT)

Key words: cattle grazing; earthworms; grasslands; visual examination; management

Abstract
Grasslands can play a crucial role in mitigation of global warming by serving as carbon sink. Nevertheless, to achieve the grasslands’ potential, sustainable management is of the utmost importance as it determines system’s productivity and ecosystem services. Due to the increasing demand for animal products in developing countries, grazed areas increase exponentially in the tropics, mainly due to unsustainable management leading to low productivity and soil degradation. We evaluated the impact of intensive rotational grazing management (IRG) on early indicators of soil quality following land-use change based on on-farm observations of visual soil characteristics using two different widely used assessment methods: visual soil assessment-VSA and visual evaluation of soil structure-VESS. Correlation of visual methods were combined with measurements of soil macrofauna abundance and physical properties (e.g. bulk density, soil porosity). The IRG established in two study sites in Colombia was compared with traditional long-term continuous grazing with low stocking rate (1 LU ha-1). The IRG was based on rapid (1 day) cattle grazing in paddocks with high stocking rate (180 LU ha-1) followed by 60 days of recovery. In both study sites, IRG increased considerably total stocking rate to 4 LU ha-1 while improving grassland composition by enabling more valuable species, which contributed to soil quality and increased grassland productivity. Both VSA and VESS discriminated IRG-managed sites in less than one year after IRG adoption. Our results demonstrate that visual soil assessment is a useful mean for evaluation of soil quality and grassland productivity. Furthermore, VSA and VESS seemed to be more suitable in discriminating among management in early stages, when compared to commonly used soil physical properties, and were strongly correlated mainly to the abundance of earthworms. Furthermore, our study confirms the importance of grazing management in soil quality and ecosystem productivity/sustainability.

Introduction
To satisfy the growing demand for animal products in recent years, particularly in developing countries, large areas have been deforested and converted to pastures (Lerner et al., 2017). Consequently, over 30% of Colombia’s surface (similarly to other tropical countries) is currently covered by grazed grasslands with mean animal stocking rates as low as 0.6 livestock units (LU) ha-1 (Murgueitio et al., 2011; Lerner et al., 2017). As further deforestation is recently no longer a socially, environmentally and economically acceptable option to increase the production, it is essential to increase the outputs per unit of land area, while simultaneously reverting soil degradation (Lerner et al., 2017).

As a promising alternative to common continuous grazing, short-duration intensive rotational grazing (IRG) across multiple paddocks has been successfully used to increase animal productivity (to >4 LU ha-1) without detectable negative impact on soil quality within one year after the IRG adoption (Teutscherová et al., 2021); i.e. increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG). The IRG consists of high stocking rates within the rather small paddocks, short periods of grazing and long periods of pasture recovery (Teague et al., 2013). Besides the increased animal and pasture productivity, the most commonly discussed
environmental benefits of IRG are increased soil organic carbon (SOC) content, reduced soil compaction, higher soil water retention and improved soil aggregation (Teague et al., 2013; Park et al., 2017; Waters et al., 2017; McDonald et al., 2018), and the increase of soil macrofauna (Teutschervá et al., 2021), i.e., increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG).

Nevertheless, to provide robust scientific evidence of IRG benefits is challenging due to the lack of replicated experiments, and the limited results differ greatly from the on-farm observations (Conant et al., 2017). Species composition, and mineral nutrient availability can lead to losses or gains of soil carbon. Because of the large annual carbon fluxes into and out of grassland systems, there has been growing interest in how changes in management might shift the net balance of these flows, stemming losses from degrading grasslands or managing systems to increase soil carbon stocks (i.e., carbon sequestration). In the Colombian Eastern Plains (Teutschervá et al., 2021), i.e., increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG), similarly to other tropical areas (Alfaro-Arguello et al., 2010; Ferguson et al., 2013). Mexico typically employs extensive grazing, annual pasture burns and frequent applications of agrochemicals, threatening biodiversity and long-term productivity. A small group of innovative ranchers in the Central Valleys are converting to holistic management through careful land-use planning, rotational grazing, diversified forage, and diminished use of purchased inputs. We compared the sustainability of 18 conventional and seven holistic, dual-purpose ranches, using three sets of sustainability metrics. First, we combined semistructured interviews and field observations to better describe the two production systems and to calculate an "Organic Conversion Index" (OCI, some farmers initiated to manage their farms more holistically by adopting IRG management, observing increases of both forage and animal productivity. As large areas of grazed grasslands in the tropics are located in remote areas, where soil analysis is logistically and economically unfeasible, on-farm observations and soil assessments have been gaining on importance in evaluation of the management impacts on soil quality (Guimarães et al., 2011, 2017; Emmet-Booth et al., 2016). Quick, cheap and can be used by farmers, gardeners, consultants and the scientific community. However, European and Brazilian users of one such method, viz. visual evaluation of soil structure (VES). Here we focused on variables, which can be assessed by farmers or local agronomists on field to evaluate the effect of IRG using paired farms comparisons. Visual evaluation of soil structure (VES) and visual soil assessment (VSA) were applied and compared with the analysis of selected soil physical properties (bulk density and soil porosity, which are often the most representative variables indicating soil compaction) and with the abundance of ecosystems engineers (earthworms, termites and ants), reported in previous studies, to evaluate its usefulness for grasping the impact of grazing management in early stages after their adoption. We hypothesize that (i) VSA and VESS will differ between IRG and traditionally-managed farms, and (ii) both visual techniques will correlate with soil macrofauna and soil physical properties.

**Materials and Methods**

The study was performed at two sites, which were described previously (Teutschervá et al., 2021), i.e., increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG), both located in Colombian Eastern Plains. At each site, paired adjacent farms were selected for the comparison of IRG management with high stocking rate (>4.2 LU ha⁻¹), with traditionally managed reference farm with low (<1 LU ha⁻¹) stocking rate. The traditional management consisted of continuous grazing (Morichal site) or one week of grazing followed by two weeks of pasture recovery (Villasol site). The IRG management (on both sites) was based on short grazing period (1 day) and long pasture recovery (60 days) with high stocking rates within paddocks (>180 LU ha⁻¹). A transect was laid across each of the our farms and soil and macrofauna samples were collected along each transect at least 100 m apart. Whole four samples were collected in each of the reference farms, eight samples were taken in each IRG farm due observed higher variability.

Visual soil assessment (VSA) as described by (Shepherd 2003) was performed by scoring observations of soil texture, structure after a drop test, visible soil porosity, soil color and mottling, earthworm activity, rooting depth, surface ponding and crusting, soil erosion and surface microrelief...
to produce an overall score of soil condition. The structure after a drop test (drop/shatter test) was determined by dropping a block of soil (20 x 20 x 5 cm) three times from a height of one meter onto a large tray. Soil aggregates were then organized based on their size and scored 0 (degraded) to 2 (favorable conditions). The assessment of VESS followed the methodology described by (Guimarães et al., 2011). In brief, soil blocks at least 15 cm thick were extracted from the sides of the macrofauna monolith (to a 20 cm depth) with a spade and manually broken down along the natural fracture lines on top of a plastic tray. Soil layers with distinct properties were identified and their depth was measured to be scored separately. Then, scores were assigned by comparing the size and appearance of aggregates, visible soil porosity and roots, appearance of soil after break-up, and the appearance of soil aggregates (approximately 1.5 cm in diameter) of the sample with the VESS chart (Guimarães et al., 2011). Each property was scored from 1 (optimal structure) to 5 (very poor structure) separately in each soil layer. The score of the whole soil block was calculated as a weighted mean of both layers.

Data on soil macrofauna (earthworms, ants and termites, which can be easily recognized by farmers) and on soil bulk density and porosity were obtained from previously published work (Teutscherová et al., 2021), i.e., increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG. Briefly, soil macrofauna was manually extracted from 0-10 cm and 10-20 cm soil layer using soil monoliths (25 x 25 x 20 cm depth) according to Tropical Soil Biology and Fertility Institute (TSBF) method. In this study, we report the mean sum of both soil layers, thus, referring to macrofauna abundance as the number of individuals per square meter to the depth of 20 cm. Bulk density and porosity were determined using metal soil cores.

For the statistical analysis, data from both sites were combined and the differences between IRG and traditional management were assessed by linear mixed model with the grazing management (IRG and TM) as fixed factor and site as random factor. The level of significance was set at p<0.05. The correlation between soil macrofauna and soil properties with VESS and VSA was evaluated according to Person’s correlation coefficient using SPSS 22.0.

Results
The VSA scores and VESS scores were higher and lower (p<0.001), respectively, in IRG-managed farms compared to traditionally-managed adjacent farms. Both VSA and VESS correlated with the abundance of earthworms (Fig. 1), while VESS was also correlated with the abundance of termites (r=-0.603; p<0.001) and soil bulk density (r=0.735; p<0.001). Strong correlation was also observed between bulk density earthworms (r=0.665; p<0.001), termites (r=-0.457; p<0.01), and total macrofauna abundance (r=-0.451; p<0.05).

![Figure 1](image-url) - Pearson’s correlations of earthworm abundance with visual soil assessment (VSA) and visual evaluation of soil structure (VESS) scores (a); the scores of VSA under intensive rotational grazing (IRG) and traditional grazing (control) (b); the scores of VESS under IRG and control grazing management (c).
Discussion
Both VSA and VESS distinguished clearly IRG from the traditionally-managed farms with better soil structure under IRG. While other authors have demonstrated the positive effect of grazing intensification on soil macroinvertebrates in the tropics (Decaëns et al., 2004; Webster et al., 2019), to the best of our knowledge, no studies have assessed the capacity of visual soil evaluation techniques (either VSA or VESS) to detect impacts of grazing management in such an early stage since its adoption on soil structure.

A previous study has identified a positive link between the abundance of soil macrofauna (particularly earthworms) and improved soil physical properties (Teutscherová et al., 2021). Increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG), which was also confirmed by the present study, where strong correlation of earthworms abundance with both VSA and VESS was also observed, clearly indicating the crucial role of earthworms in soil structure formation, hence for soil functioning (Lavelle et al., 2006). Nevertheless, it remains unclear whether the improved structure is the result of (i) reduced compaction by the IRG, which allows for higher abundance of earthworms and forage productivity, or (ii) increased forage production translated in higher root decay and dung and urine input, which in turn promote higher abundance of soil macroinvertebrates reducing soil compaction (Decaëns et al., 2004), as discussed previously (Teutscherová et al., 2021) i.e. increasing animal productivity while maintaining or improving soil quality and ecosystem services. We investigated the impact of intensive short-duration rotational grazing (IRG). Similarly, the higher incidence and extension of mottles and redoximorphic colors as observed visually during VSA evaluation under IRG, may indicate lower vulnerability of IRG-managed farms to waterlogging, which may be attributed to (or be a result of) higher abundance of earthworms and higher root density.

Regardless of the causal links, IRG was associated with both higher animal productivity and better soil quality, hence confirming potential to improved forage-based agriculture in the Colombian Eastern Plains, where cattle grazing is the most common agricultural activity. Furthermore, the capacity of visual techniques of soil evaluation is of crucial importance in this remote areas, especially in the early stages after the IRG management adoption because early visible results are an additional motivation for local farmers and agronomists to adopt sustainable intensification strategies preventing degradation processes.

Acknowledgements
This work was implemented as part of the CGIAR Research Program (CRP) on Climate Change, Agriculture and Food Security (CCAFS), and the Livestock CRP which are carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations. Financial support was also obtained from Integral Grant Agency of Czech University of Life Science Prague (no. 20205003). The authors would like to acknowledge support from the UK Research and Innovation (UKRI) Global Challenges Research Fund (GCRF) GROW Colombia grant via the UK’s Biotechnology and Biological Sciences Research Council (BB/P028098/1).

References


Interventions for mitigating drought-related livestock mortality in Africa’s pastoral areas: a review of their relevance and effectiveness with special reference to Kenya

Dabasso, B. H

Kenya Agricultural and Livestock Research Organization, Marsabit Research Station

Key words: drylands; drought impacts; livelihoods; pastoralists; pastoral livestock production

Abstract
One of the key challenges facing pastoral livestock production in Africa’s drylands is the recurring drought which triggers shortage of grazing resources and massive losses of livestock. Though the pastoralists have traditional drought coping mechanisms, the changing land use, insecure land-tenure arrangements, and the declining natural resource base, have undermined the effectiveness of the mechanisms and worsen the drought impacts. Several interventions have hence been implemented over the years to mitigate the increasing drought impacts and to create more resilient pastoralist societies. Focusing on Kenyan pastoral areas, this study reviewed the relevance and effectiveness of various interventions in reducing the drought-related livestock mortalities. The results show that drought interventions such as destocking programs, supplementary feeding, provision of early warning information, water development, and veterinary services were commonly implemented, but often at the late stage of drought cycles with little emphasis on sustainability.

Introduction
Drought is a deficiency or lack of rainfall over an extended period, often accompanied by high or above-normal temperatures (Dai 2011). It occurs in nearly all agro-ecological zones, but is commonly reported in drylands (Begzsuren et al., 2004; Kazianga et al., 2006; Vetter 2009; Biradar and Sridha 2009; Coppock 2011; Twidwell et al., 2014) and found to cause huge livestock losses in pastoral production systems (Oba 2001; Catley et al., 2014; Rao et al., 2015). Owing to the drought-related livestock losses, pastoral herd growths are defined as “boom and bust” cycles, in which there are years of gradual herd increase, followed by sudden and widespread livestock mortalities caused by long-lasting droughts (Desta and Coppock 2002; Coppock et al., 2008).

Despite the drought-driven shocks, pastoralists have been living with droughts since time immemorial and employed elaborate coping strategies including livestock mobility across landscapes, herd splitting, establishing grazing reserves, building of friendship and social alliances, and supplementary feeding of weak and lactating animals (Oba and Lusigi 1987; Butt et al., 2009; Farrell et al., 2009; Lengarite et al., 2014). Pastoralism itself can be understood as sui generis, a highly reliable production system that intelligently uses unreliable environments through coping mechanisms such as herd mobility (Kratli and Schareika 2010). Nevertheless, the effectiveness of pastoralists’ practices for coping with droughts has eroded over time (Ouma et al., 2011), due to changing land use that limits the livestock mobility for opportunistic utilization of variable grazing resources (Lengaiboni et al., 2010; Smalley and Corbera 2012). The situation is likely to be aggravated by changing climate, which is generally assumed to increase drought frequencies (Dabasso and Okoti 2015) though the implications of climate change on weather patterns may also vary with regions (Touchan et al., 2011). The increased drought frequencies imply that pastoralists have little time to build herds during the post-drought periods and therefore the recovery effort from drought stress is compromised (Ahmed et al., 2002).

Increasing drought-related livestock mortalities in pastoral areas call for appropriate interventions that can create more resilient pastoral societies. However, drought interventions are often implemented ad hoc by state or non-state actors with little understanding of their relevance, effectiveness and long-term sustainability. More
often than not, the focus has been responding to crisis rather than developing integrated long-term programs for managing drought risks (Wilhite 2000). This study reviewed the relevance and effectiveness of various drought interventions implemented by development actors in pastoral areas. The purpose is to identify appropriate intervention(s) that development planners and decision-makers could consider in their effort to reduce the drought-related livestock losses in pastoral production systems. The study focuses on the pastoral system of Kenya, one of the livestock production systems, where several state and non-state actors have dedicated a colossal amount of resources to avert drought impacts and build the resilience of pastoral societies to the climate variability, yet the losses have persisted. For example, in northern Kenya where pastoralism is the dominant livelihood, humanitarian organizations spent USD 2,502,200 in implementation of various livestock interventions during the drought of 1999-2000 (Aklilu and Wekesa 2001). In spite of the huge financial investment, the impacts of drought, particularly on livestock losses have continued unabated and even become more devastating in recent years. For instance, the drought of 2005/2006 caused 14 to 43% livestock mortality (depending on locations and livestock species) in the southern rangelands of Kenya (Nkedianye et al., 2011). In northern Kenya, the drought of 2008/2009 caused about 60% and 40% cattle and goats (sheep and goats) mortality, respectively (Zwaagstra et al., 2010). In spite of the economic losses, the country lacked clearly defined interventions for reducing the drought impacts and the stakeholders usually implemented short-term initiatives on an ad-hoc basis to salvage the livelihoods.

Materials and Methods
The study was based on a comprehensive analysis of peer reviewed journal papers, reports and other literature, to identify and examine various drought interventions. Using keywords such as drought, interventions, programmes, and livestock loss/mortality, the literature were searched in the internet database including Google Scholar and Web of Science. The results are important in drawing lessons on the relevance, effectiveness and sustainability of drought interventions in pastoral production systems.

Results
Destocking programs
Destocking is a drought intervention in which pastoralists are facilitated to sell lean animals and so that they have some cash to buy food or feeds that can maintain the remaining animals during the period of a drought. In destocking programs, lean animals can be purchased (in exchange of cash, feeds or drugs), slaughtered locally and the meat distributed to the most vulnerable households or local schools (Morton et al., 2005). Alternatively, transport subsidies are offered by non-governmental organizations to traders who may purchase animals from remote areas at the peak of a drought period and transport the animals to terminal markets for sale (Morton and Barton 2002). In addition to providing financial assistance to pastoralists, destocking programs helps in matching the available pasture with the livestock population. However, a study by Watson and Binsbergen (2008) evaluated the effectiveness of an emergency livestock off-take implemented by the Veterinaries Sans Frontieres (VSF)-Belgium in Turkana (Kenya) during the drought of 2005 and observed that several limitations including too low prices (ranging from Kshs 350 to 800) offered that have little financial help to the pastoralists. They further observed that the program was done on “first-come” basis and those with little social and political contacts were left out.

Destocking programs are also likely to fail if there is no reliable avenue in which the pastoralists can restock in the post-drought period (Ahmed et al., 2002). In most cases, pastoralists have limited avenues to restock and therefore they prefer to keep animals through a drought especially if there is uncertainty how long the drought could take as it is costly to destock and later restock when the condition improves (Campbell et al., 2006), although they resort to stress-sale syndrome when the condition deteriorates (Barret et al., 2003).

Supplementary livestock feeding
Supplementary livestock feeding is the supply of additional feeds to aid in maintaining the body condition of livestock especially during periods of feed scarcity. Its benefits are numerous and including salvaging breeding stocks which are crucial in the post-drought recovery process. A study by Bekele and Abera (2008) conducted an impact assessment of the supplementary livestock feeding programs implemented by the USAID Pastoralist Livelihoods Initiative in southern Ethiopia during the 2007/2008 drought and concluded that there were lower mortality rates, high calf survival and milk supply in the supplementary-fed cattle compared unfed cattle.

Results
Destocking programs
Destocking is a drought intervention in which
They further indicated that the benefits of the supplementation program outweighed the costs.

However, there are some challenges associated with supplementary livestock feeding as a strategy for minimizing the drought-related livestock mortality. Based on the experiences of the development agencies in northern Kenya in their response to the drought of 1999/2000, Aklilu and Wekesa (2001) concluded that supplementary feeding was costly, labour intensive and has other challenges associated with feed spoilage. In their analysis of opportunities and challenges of supplementary livestock feeding in drylands, Muller et al., (2015) also observed that although the strategy has potential in keeping livestock numbers constant under variable grazing conditions, it could decouple livestock-vegetation dynamics and eventually lead to overgrazing and decreased rangeland productivity. They concluded that it is important to continue providing feed supplements even after the drought to allow pasture regeneration and avoid environmental degradation.

Moreover, when supplementary feeds are cultivated alongside crops, there could be a possibility of compromising food security (FAO 2009; Erb et al., 2012). About 33% of world croplands are already under feeds cultivation (FAO 2012), and with the growing demand for livestock products (Delgado 2003), feeds production could take up more land as the demand presents livestock producers with an opportunity for intensified production in the tropics and sub-tropics (McDermott et al., 2010; Millar and Photakoun 2011; Stür et al., 2013).

**Drought early warning information systems**

One of the key interventions for reducing the drought impacts is the provision of early warning information that provides a prediction of future climatic conditions so that appropriate actions are taken. It was on this understanding that the Arid Lands Resource Project, a World Bank-supported project, implemented in about 11 arid districts of Kenya, employed local monitors to report the status of pasture, water, animal health and production, and markets, among other indicators, to provide early and coordinated drought responses. Although, the World Bank reported the project performance as “satisfactory” (World Bank 2005), a study by Sinange (2007) indicated that most of the food security and the early warning information systems used in East Africa are unreliable due to weak data and governance structure for effective communication (Pulwarty and Sivakumar).

**Water provision**

The water scarcity in drylands usually worsens during the period of a drought and becomes a threat to livestock survival. In such circumstances, government and non-governmental organizations often resort to providing water tankering, or drilling of emergency boreholes. One main challenge that could emanate from such initiatives is the degradation of the environment. Studies (Sasaki et al., 2005; Hoshino et al., 2009) have shown that rangeland ecosystems around frequently used water sources would likely experience high grazing intensity which can negatively impact vegetation composition and cover. To avoid localized rangeland degradation around frequently used water sources, development planners should evenly-distribute water points so as to allow uniform grazing of the rangelands. Nevertheless, the rangeland degradation around major or frequently used water sources is a contested view. A study by Fernandez-Gimenez and Allen-Diaz (2001) suggested that there would be urines and faeces deposition by the grazing animals which could enrich soil nutrients and thus help in regeneration of the rangeland.

Water development as a drought response initiative in pastoral areas has significant cost implications. A study by Morton et al., 2005 suggested drilling boreholes as a drought response is only justifiable if the value of livestock saved is comparatively higher than the cost of drilling the borehole. The authors further indicated that many pastoralists do not afford the cost of maintaining a water source such as a borehole unless they get external support and therefore it is important to understand the cost involved to drill and maintain a borehole. A similar opinion was echoed in a study by Obá and Lusigi (1987) in which it was indicated borehole development in pastoral production systems should consider the ability (both technological and economic) of the pastoralists to maintain and service the borehole. The authors further suggested that hand-dug wells could be more suitable in pastoral areas as they are cheap and easy to maintain and also have little impacts on the adjacent grazing areas compared to boreholes.

**Provision of veterinary services**

Provision of veterinary services is also one of the key drought interventions in pastoral areas. This is premised on the fact that the risk of livestock diseases could increase with drought and in the
immediate post-drought period as weak animals are vulnerable to disease and parasitic infections. A study conducted by Catley et al., (2014) in the pastoral regions of Ethiopia concluded that about 28% of total livestock mortality experienced during periods of drought is caused by diseases. Veterinary interventions are thus provided to support pastoralists to protect or treat their animals, especially the breeding stock. During the drought 1999/2001, several organizations supplied drugs to pastoralists in Moyale, Marsabit and Samburu areas of Kenya and asked them to pay in form of goats which were also slaughtered and the meat distributed to villages and schools (Morton et al., 2005). A study by Catley et al., (2004) observed that whereas provision of veterinary services is one of the important drought interventions, it is being constrained by the limited number of professional staff, poor infrastructure, insecurity and the high transaction costs. To overcome the challenge of limited professional personnel in the delivery of veterinary services in the pastoral areas, the government of Kenya trained community-based animal health workers (CBAHWs) who are tasked with the responsibility of primary animal health care. This notwithstanding, the statutory body concerned with veterinary services in Kenya has opposed to the service delivery by CBAHWs claiming that the approach is not in-line with the existing legal structure (Mugunieri et al., 2004). This may jeopardize the provision of the veterinary services as drought intervention in the pastoral areas of Kenya.

Conclusions
Interventions for reducing the drought-related livestock mortality in pastoral production systems practised in Africa’s drylands include destocking programs, supplementary feeding, provision of early warning information, water development, and veterinary services. While these interventions are useful in salvaging pastoral livelihoods in drought emergencies, there might be shortcomings that result from poorly designed methodological approach, high costs involved, negative environmental consequences, and inconsistency with the pastoralists’ livestock production objectives and the existing legal structure. The study recommends analyses of the pros and cons of each drought intervention prior to their implementation so as to undertake sustainable and more effective intervention approaches.

Acknowledgements
The study was undertaken within the framework of a collaborative research project, ‘Reduction of Post-Harvest Losses and Value Addition in East African Food Value Chains’ (RELOAD), funded by the Germany Federal Ministry for Economic Cooperation and Development (BMZ).

References


Uses and knowledge of plant species by mongolian herders in the gobi desert and identification of species of interest for planting

Barnes, A.1,2; Taugourdeau, S. 1,2; Bazan, S. 1,2; Rayot, V. 3; Enkhjargal Ts. 4.

1CIRAD, UMR SELMET, Montpellier, France ; 2UMR SELMET , Univ Montpellier , INRAE, CIRAD Insitut agro , Montpellier France ; 3Orano, Chatillon, France ; 4Badrakh Energy, Ulaanbaatar, Mongolia

Key words: Mongolia; pasture species; fodder use; human use; planting

Abstract
In Central Asia, many projects propose to establish single-species saxaul (*Haloxylon ammodendron* (C.A. Meyer) Bunge) plantations. An ethnobotanical survey was carried out among herders in Ulaanbadrakh, in the Dornogobi province, and herders in Gurvansaikhan, in the Dundgobi province in the Gobi Desert (Mongolia). The aim of this survey is to verify the interest of saxaul for the local populations, and to identify other woody species of interest for planting. Herders were questioned about the use of plant species from the Gobi grazing lands: livestock feed, human food, and then about plant species non-eaten by livestock and those that could be toxic to them. A total of 75 species and 413 uses related to these species were cited. We retained the species cited by at least 25% of the herders: 8 species of interest were selected, then sorted according to the number of associated positive uses, while focusing on the species cited in Ulaanbadrakh (area of interest in the Dornogobi). Saxaul appears to be the most numerous woody species for the herders and their livestock. Three other woody species of interest have also been identified. These results show that there is a high diversity of plant species used. It would be interesting to investigate the interest of a multi-species plantation for herders and their livestock in future surveys.

Introduction
In Central Asia and Mongolia, many projects propose to establish single-species saxaul (*Haloxylon ammodendron* (C.A. Meyer) Bunge) plantations to combat desertification (Kleine et al., 2009), for the restoration of dryland forests (Meshkov et al., 2009 in Stanturf et al., 2020), as well as for ecological compensation of mining (Lezak, 2019). In the Gobi Desert in Mongolia, the main land-use is semi-nomadic livestock farming with multi-species herds composed of camels, goats, sheep, horses and cows (Walton, 2010). Then, plantation projects should be adapted to this use of the territory and to this extensive livestock farming.

Saxaul forests cover 25.3% of the Mongolian forest area (Suvdantsetseg et al., 2008), and they are the most widespread in the Gobi Desert. Saxauls are adapted to dry and arid climates, primarily due to a deep and wide root system (Suvdantsetseg et al., 2008). Thus, saxaul seems to be adapted to harsh local pedoclimatic conditions, which benefit herders and their herds as it can be used as fodder for livestock (Suvdantsetseg et al., 2008). Other woody and herbaceous species also compose the rangelands of the Gobi: consider them for planting projects could be interesting for local population, by meeting their need by providing food or fodder for their livestock.

The objective of this study is to determine the right species, i.e. local plant species adapted to the pedoclimatic conditions that also benefit the populations and their activities. The herders are the key actors in guiding the choice of the species for local pastures since they are the primary users of plant species in the Gobi region. We therefore determined the identification of preferred species for planting based on an ethnobotanical survey conducted among herders.

Materials and Methods
The main location of interest was the *Ulaanbadrakh soum* (district), in the Dornogobi *aimag* (province), thus interviews are conducted with herders in this territory to identify local species. Interviews conducted in *Gurvansaikhan soum* (Dundgobi *aimag*) allow comparison of local botanical knowledge between the herders of...
the two soums. Dornogobi is a mosaic of desert steppes and semi-deserts, with some areas of real desert, and Dundgobi is a steppe desert region, with some semi-desert areas in the south (Chimed-Ochir et al., 2010).

We met 13 herders from Ulaanbadrakh soum and 12 herders from Gurvansaikhan soum. Herders were asked to freely quote species they know according to the following use categories: (i) source of food for livestock; (ii) source of food in winter for livestock; (iii) source of human food; (iv) not eaten by livestock; (v) may be toxic to livestock. The data collected are supplemented by research pertaining to the Mongolian vernacular name(s) and Latin name with the support of local botanists and the use of “The Virtual Flora of Mongolia” (FloraGREIF, 2010). We used the taxonomic reference from “The Virtual Flora of Mongolia” (FloraGREIF, 2010) and “The Flora of China” (eFloras, 2015).

The analytical work is organized as follows: (i) graphical quantification of the occurrence of species among herders’ citations; (ii) selection of species cited by at least 25% of the herders; (iii) graphical representation of the distribution of uses for the selected species; (iv) ranking of the selected species according to the number of citations from Ulaanbadrakh herders (area of interest) and the number of associated positive uses.

Results

Table 1 shows the number of plant species and uses cited by the herders of Ulaanbadrakh, Gurvansaikhan and the two regions combined. In total, 75 species were cited and we found the Latin names for 50 of them. Vegetation seems different between the two regions: among the 75 cited species, only 12 species are common to both regions.

Table 1: Number of plant species and uses cited by herders, number of common species cited in the two study.

<table>
<thead>
<tr>
<th></th>
<th>Number of species cited</th>
<th>Number of uses cited</th>
<th>Number of cited species in common</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulaanbadrakh</td>
<td>59</td>
<td>234</td>
<td>12</td>
</tr>
<tr>
<td>Gurvansaikhan</td>
<td>28</td>
<td>179</td>
<td></td>
</tr>
<tr>
<td>Both regions</td>
<td>75</td>
<td>413</td>
<td>/</td>
</tr>
</tbody>
</table>

Occurrence of species cited by herders

Figure 1 shows the occurrence of species among the citations of the herders in terms of percentage. A percentage of 100% in the two regions means that the species were cited by all 25 herders. From this graph, species of interest are selected. Species whose Latin names have not been found are excluded, as are cultivated species (oats, maize, wheat) that do not occur naturally in the Gobi Desert.

Figure 1: Occurrence of species among the citations of herders in Ulaanbadrakh, Gurvansaikhan and the two soums combined (1)
**Uses of selected species**

Figure 3 shows the total number of cited uses by species of interest, and the height of sections of each bar on the graph as the importance of each use. Concerning species that can be toxic to livestock: *Allium mongolicum* has been cited as toxic, especially for goats and sometimes for sheep if ingested in too large quantities; sheep and goats could become intoxicated by eating too much *Allium polyrhizum*. Concerning saxaul, it can be avoided by small livestock (goats and sheeps) because it contains ticks and they usually cannot ingest it because it is often too high off the ground for them. According to another herder, cows do not eat saxaul.

**Figure 2:** Occurrence of species among the citations of herders in Ulaanbadrakh, Gurvansaikhan and the two soums combined (2)

**Figure 3:** Relative importance of use categories in relation to the total number of uses of each selected species
Ranking of species according to the number of citations from Ulaanbadrakh herders and positive uses

Table 2 summarizes the information related to the 8 species mutually selected among herders at both geographic areas and ranked according to number of uses and number of herder references.

**Table 2:** Ranking of species of interest according to the greatest number of positive uses, their respective Mongolian vernacular name(s) and Latin name, and vegetation type. HP: “herbaceous perennial”; W: “woody”.

<table>
<thead>
<tr>
<th>Mongolian vernacular name(s)</th>
<th>Latin name</th>
<th>Type</th>
<th>Number of positive uses</th>
<th>Number of citations in Ulaanbadrakh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khumuul</td>
<td>Allium mongolicum Turcz. ex Regel</td>
<td>HP</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>Taana</td>
<td>Allium polyrhizum Turcz. ex Regel</td>
<td>HP</td>
<td>40</td>
<td>13</td>
</tr>
<tr>
<td>Khylagana</td>
<td>Stipa glareoosa P. Smirn.</td>
<td>HP</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Zag</td>
<td>Haloxylo ammodendron (C.A. Meyer) Bunge</td>
<td>W</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Khazaar</td>
<td>Cleistogenes songorica (Roshev.) Ohwi</td>
<td>HP</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>(Bor)budargana</td>
<td>Salsola passerina Bunge</td>
<td>W</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Kharmag / Tovstog</td>
<td>Nitraria sibirica Pall.</td>
<td>W</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Agi</td>
<td>Artemisia frigida Willd.</td>
<td>W</td>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

Discussion

The results of the ethnobotanical survey highlight the plurality of plant species used and known by the herders in the study areas. A total of 75 species were cited, corresponding to 413 uses. The diversity of species used by the herders was determined thanks to the local botanical knowledge. This diversity of species and uses suggests the potential benefits that can be brought by multi-species plantations within projects. From the species cited by the herders of Ulaanbadrakh and Gurvansaikhan soums, a list of 8 species is established, based on their occurrence among citations and the uses and knowledge associated with them. This list includes 4 perennial herbaceous and 4 woody species, and saxaul appears as the first woody specie of interest for Ulaanbadrakh soum. However, 3 other woody species also appear interesting, in the following order: Salsola passerina, Nitraria sibirica, and Artemisia frigida. According to observations in natural saxaul forests, Nitraria sibirica can coexist with saxaul. Planting projects should consider this diversity by including those other species to benefit local populations and livestock farming.

The present study was a first exploratory survey of species used by herders and livestock in these study regions. This survey presents information on the amount of species diversity and multiple uses of them. Further surveys with herders in these regions along with scientific investigations of these species need to be continued. Methods of production and plantation should also be investigated.

Acknowledgements

We are grateful to all the herders who agreed to answer the survey, to Badrakh Energy and the Mongolian National Federation of Pasture User Groups of herders for all the logistics, support and assistance provided for the fieldwork in the Dornogobi and Dundgobi soums, respectively, and Orano for granting permission to publish our results.

References


THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES

Topic: Developing environmental services payments schemes for grassland in China and Mongolia
Management changes and strategies to improve the environmental services from grasslands in northern China and Mongolia

Kemp, DR¹; Addison, J²; Behrendt, K¹³; Udval, G⁴; Lkhagvaa, D⁵; Han, GD⁶; Li ZG⁶; Li P⁷

¹Graham Centre for Agricultural Innovation, Charles Sturt University, Orange, NSW, Australia;
²James Cook University, Townsville, Qld, Australia;
³Harper Adams University, England;
⁴Research Institute for Animal Husbandry, Ulaanbaatar, Mongolia;
⁵Mongolian University of Life Sciences, Ulaanbaatar, Mongolia;
⁶Inner Mongolia Agricultural University, Hohhot, Inner Mongolia Autonomous Region, China;
⁷Institute of Grassland Research, Hohhot, Inner Mongolia Autonomous Region, China

Key words: China; Mongolia; grassland rehabilitation; environment; PES

Abstract

The grasslands of Mongolia and northern China are part of the vast Eurasian grasslands that extend from east Asia to eastern Europe, with many common problems. Grassland degradation and herder livelihoods in the steppe regions of China and Mongolia are widely acknowledged as major issues that need to be improved. The core problem is too many animals are now grazing grasslands, initially driven by significant policy changes, and decisions that assumed more animals would lift herder incomes. Problems are accentuated by poorly defined property rights over the land. The effectiveness of current Government Programs aimed at reducing grazing pressures has been questioned, especially for their ability to deliver better environmental outcomes without impacting herder livelihoods. This panel session examines ways to understand the opportunities for improvement of grasslands. This first paper outlines some general aspects of the pastoral sectors, and management responses and strategies that can improve the services from grasslands.

Introduction

Since 1950 the average stocking rate in sheep units in China has risen four-fold, while in Mongolia total sheep units have doubled since 1990 (Brown 2020, Chapter 3; Kemp 2020, Chapter 2). The increase in livestock numbers has followed major changes in Government and the belief that increasing animal numbers will increase herder household incomes, but that had major deleterious effects on grasslands increasing the proportion of less-desirable plant species and reducing plant and per head animal productivity (Kemp 2020, papers in this session). In China, 90% of the grasslands have been regarded as degraded (Kemp & Michalk, 2011) while in Mongolia the problem is less, but significant in central regions, especially near towns and the city (Densambuu 2018). Both countries now have policies designed to rehabilitate the grasslands that focus on improving the environmental services from grasslands as well as improving herder household incomes. The aims of this paper are to introduce the issues influencing the condition of grasslands of northern China and Mongolia and the solutions investigated to improve them (Kemp et al., 2013). As discussed here, management changes can help livestock system changes move in desirable directions, but there is the need for Government intervention to augment those changes to achieve grassland environmental goals. Other papers in this panel session will then deal in more detail with policy investigations designed to improve environmental services.

Environment

The main grassland areas of China (~400m ha) and Mongolia (~130m ha) are in cold temperate regions. Around two-thirds of the annual precipitation (50-500mm) occurs over summer when temperatures are above freezing. Temperatures vary from 30-40°C in summer to -40°C or less in winter, and altitudes from 1000-
4500m. Snow falls do occur through winter and in some years, these are heavy enough to prevent grazing of the limited, poor quality frosted grass. As animals normally lose 20-30% of their liveweight through the 8-9 months of cold weather, their mortality can be high during snow falls. Heavy snow falls often follow a summer where grass growth was poor. In Mongolia, this is one form of a dzud, where in recent times half the animals in the country have died. In China, warm sheds are now widely used to help protect animals in winter and the use of improved fodder supplements is more widespread, along with other management changes that have improved animal productivity (Kemp 2020, Chapter 3). In Mongolia, livestock remain outside through winter, spending the nights in open-air shelters; meagre supplements are only given to animals that are young or obviously sick.

**Early responses**

In Inner Mongolia, the main grassland province in China, the initial response to grassland degradation was to impose five-year grazing bans in the 2000s; 70m ha were progressively closed to grazing. This followed the allocation of individual household user rights in the 1990s, to specified land areas to replace the traditional transhumant systems. Livestock numbers rapidly increased after herders were allocated user rights. The grazing bans did not work very well as ‘night’ grazing then occurred (to avoid detection). There was often no clear evidence that the state of the grassland had improved (less-desirable species still dominated) and after the ban stocking rates resumed at the former high levels. It has been evident that any changes in grassland condition often take much longer than five years (Kemp & Michalk 2011). Herders received a small payment to not graze, but the same rate was paid per hectare irrespective of the type of grassland (desert to meadow or alpine). These policies were revised in 2011 to include reducing stocking rates, imposing a grazing ban in early summer to enable some recovery in grassland condition. Grazing experiments (Kemp 2020, Chapters 8, 9, 10) found that the botanical composition of grasslands and herbage mass were in a more desirable state when stocking rates were reduced by 50% from the district average. This also meant the optimal consumption rate of grassland was only half that promoted by the Animal Husbandry Bureaux in China. For example, the optimal average consumption rate by sheep for the desert steppe grasslands (250mm, 1 t DM/ha, Kemp 2020, Chapter 8) was only 10%, while for the typical steppe (350mm, 3t DM/ha, Zhang et al., 2015) the optimal consumption rate was 20%. Consumption rates are the estimated amount eaten by a standard 50kg sheep which is generally about half the estimates of ‘utilisation’ derived from the herbage mass differences inside and outside a cage. The modelling and experiment evidence was then tested and shown to be viable in farm demonstrations (Figure 1, Kemp & Michalk 2011).
Joint XXIV International Grassland and XI International Rangeland Kenya 2021 Virtual Congress Oral Papers Proceedings

Net financial returns (ratio demonstration/control) Stocking rate ratio (demonstration/control) 2013

Figure 1: Average ratio of net income for demonstration / control farms (six villages) in relation to the ratio of stocking rates for demonstration/control farms in 2012/13. The horizontal dashed line shows where the net income of demonstration and control farms were equal.

These demonstrations combined improved feeding of supplements through winter (meadow hay, silage, grain; though not to optimal levels) while reducing animal numbers. They showed that net financial returns would be higher than controls at higher stocking rates, but if Government policies are to improve the grasslands, stocking rate reductions down to 50% did not result in any reduction in net household returns. Some incentives are needed so that herders do reduce stocking rates on the grassland. In the demonstration farms, those with apparent higher stocking rates, actually kept their animals more in sheds and did reduce their grazing, hence the reduction in grazing pressure was greater than Figure 1 would imply. Unfortunately, it wasn’t possible to accurately estimate that grazing pressure reduction.

Other modelling showed that the better way to reduce animal numbers, was to cull the least productive animals. Herders do not normally do this, they let traders select the animals they wish to buy. Simply culling unproductive animals often achieved a 50% reduction in animal numbers and an increase in net incomes (Kemp & Michalk 2011). The feed requirements of animals could also be better managed by changing lambing / calving times to late spring. This was initially shown with models, then tested on demonstration farms, and is now a practice being implemented in some districts; herders are given a payment to participate in this change.

A further change in China, arising from herders being given responsibility for specific areas of land, is that some herders now rent their land to others. Those renting the land then often obtain a similar net income to what they achieved with livestock. The remaining herders then have larger areas of land and the larger the land area the lower the average stocking rate (Figure 2). This effect is driven by herders having a desired number of animals, rather than a desire to have a constant stocking rate across all the land they use (Kemp 2020, Chapter 5). While this seems to be a desirable trend, the problem has emerged that any rented land tends to be used for grazing in summer and generally that is being over-grazed, while the herders ‘own’ land is kept for winter, has limited grazing in summer and is generally now in better condition.

Changes in markets in China, have meant that herders can now obtain higher prices for animals with greater quantity and quality of meat per head, achieving a desired level of income with moderate numbers of animals. In the desert steppe area of Inner Mongolia, in 2012/13, herders considered about 400 sheep were enough to have a good income, whereas across the border in Mongolia on the same grassland, herders needed 1000 sheep, to make the same income due to poorer market prices. Poor market prices add to the grazing pressure on grasslands.

In Mongolia where common grazing is practised, the areas grazed in summer tend to be overgrazed as many herders congregate there, especially around waterpoints. In winter herders have the option of registering a winter shelter for their use, which then provides informal grazing rights to the registered herder, helping to lower the grazing pressure, especially where local officials specify a minimum distance between camps. At this stage, not all herders take up the option of registering a winter grazing area, though the benefits are noticeable. These results also highlight the point...
that herders think about stocking rate in terms of the total number of animals they wish to have (Kemp 2020, Chapter 5) rather than number per hectare.

Non-Mongolian government organisations have heavily invested in the establishment of Pasture User Groups (PUGs) as a mechanism to improve grassland management (Densambuu 2018). Within target districts, grasslands are mapped and facilitation and financial support provided to local herders to encourage group decision-making around grazing. The nature and role, of local pasture user groups in pastureland governance is complex and contested (see Upton 2020) but early research suggests that where active PUGs have been established, they have provided significant social benefits (Fernandez-Gimenez et al., 2015, Ulambayar et al., 2017). An important social benefit is dzud resilience; PUG herders can have greater adaptive capacity than non-PUG herders, linking social capital and greater access and exchange of information and knowledge (Fernandez-Gimenez et al., 2015). Mixed grassland condition benefits have been noted in more productive steppe regions (Angerer et al., 2015, Reid et al., 2015) although benefits have not been found in desert steppe regions (Addison et al 2013, Angerer et al., 2015) possibly because in drier regions it will take some years for benefits to be evident (Kemp & Michalk 2011). Irrespective of their impact on grassland condition to date, pasture user groups may provide a pragmatic governance mechanism for targeting the changes in management needed to improve ecosystem services (Upton 2020).

To survive the cold winters, warm sheds have been introduced across China. These sheds vary from modified shelters through to new purpose built sheds. Often half the roof is plastic or glass and some have heating stoves. In effect, the sheds partially replace the lack of fodder which helps to reduce the rate of weight loss through the long cold season. Herders have noted that animals kept in these sheds lose less weight than those taken out to graze each day. Animal weight loss can occur from 5°C and below, reflecting the poor quality and quantity of fodder available (Kemp 2020, Chapter 3). In general Government programs are needed to fund adequate sheds as herders are continually in debt to provide household needs. Removing animals from grazing in winter does result in better outcomes for the grassland (Kemp 2020, Chapter 8). In Mongolia only open shelters, with dung on the ground to provide some insulation, are available for most of the livestock. These shelters only reduce some wind chill.

Discussion

Herder livestock and grassland management practices are changing in both Mongolia and China, in response to changing socio-economic conditions, to markets and to the recognition that the grassland condition has degraded to varying degrees, below the state desired. Herders can do things, as shown here, that are financially viable and provide the opportunity to improve the environmental services provided by grasslands. Government policies need to build upon practices that develop efficient, viable, grassland management practices that improve household incomes, and rehabilitate grasslands under lower stocking rates.

Lower stocking rates does not necessarily mean less animals. A better practice can be to manage grazing pressures on the grassland by monitoring herbage mass. The implications from the work done to date are that grazing in summer should not start until the herbage mass is above a critical value and that critical value should be used to decide when to move animals to new grazing areas through summer and early autumn (Kemp et al, 2018). Waiting until the condition of animals is visibly declining before moving them, usually means that the grassland gets overgrazed. For each of the main grassland types it is important to decide on the critical values for herbage mass below which grazing should not continue (Kemp 2020, Chapter 10). Grazing in winter can damage the grassland, restricting growth in the next summer (Kemp 2020, Chapter 8) and animals are better kept in warm sheds.

To achieve better grassland environmental outcomes, there needs to be a willingness to pay, but as shown (Brown 2020, Chapter 8) the extent that herders will respond to various programs is not always as great as the grasslands require. Latest papers in this panel session will demonstrate more detail on the options. The strategies discussed in this session are preferable to the direct regulation of livestock numbers.

Acknowledgements

The Australian Centre for International Agricultural Research funded several projects within this large program. Other projects were funded by the Chinese Government.
References


The state of grasslands across Inner Mongolia and Mongolia

Guodong Han, G.1; David Kemp2; Bulgamaa Densambuu3; Zhiguo Li4, Cuiping Gao1, Zhongwu Wang1; Zhiqiang Qu1; Mengli Zhao1, Uudval G4; Qian Wu1; Naya1 and Linxi Hu1

1 College of Grassland, Resources and Environment, Key Laboratory of Grassland Resources of the Ministry of Education, Key Laboratory of Forage Cultivation, Processing and High Efficient Utilization of the Ministry of Agriculture and Rural Affairs, Inner Mongolia Key Laboratory of Grassland Management and Utilization, Inner Mongolia Agricultural University, Hohhot 010011, China;

2 Graham Centre for Agricultural Innovation, Charles Sturt University, Orange, NSW, Australia;

3 Green Gold Animal Health Project SDC, Ulaanbaatar, Mongolia;

4 Research Institute for Animal Husbandry, Ulaanbaatar, Mongolia

Key words: Inner Mongolia, Mongolia, grasslands, environmental services, management

Abstract
Grasslands across Inner Mongolia and Mongolia, with their long history of nomadic livestock grazing, are very important natural resources for animal husbandry and environmental services. The main types of grasslands are meadow steppe (forest steppe), typical steppe (steppe) and desert steppe. Most of the grasslands are degraded due to over-grazing, which reduces animal production and the values of environmental services. Overgrazing decreases plant production, species biodiversity, ecosystem stability, soil fertility & structure, and lowers animal productivity leading to reduced household incomes. In pastoral areas across Inner Mongolia and Mongolia, degraded grasslands can be rehabilitated by better managing stocking rates. Our surveys, experiments and farm demonstrations have found that, in degraded grasslands, lower stocking rates had benefits for animal production, net incomes and environmental services. To implement these improvements across Inner Mongolia and Mongolia will be challenging to avoid deleterious trade-offs with livelihoods as it will require changes in herder practices. Further research and demonstration are required to develop locally relevant systems.

Introduction
Grasslands are 54% of the world’s total terrestrial lands providing major food sources, other goods and environmental services for pastoral areas and the wider community (Estell et al., 2012). In Inner Mongolia and Mongolia, grasslands are the major natural resource occupying 70%, and 72% respectively, of the total land. Livestock grazing on grasslands has a long history in Inner Mongolia and Mongolia, where many people depend on grasslands for their livelihoods. Traditional nomadic grazing of livestock did maintain the grassland in a sustainable condition, but since 1950 the livestock numbers (as sheep equivalents) have increased 4x in China and since 1990 by 2x in Mongolia, resulting in overgrazing and grassland deterioration (Kemp 2020, Brown 2020). Today, the main question is, what is the trade-off between grassland rehabilitation and herder livelihoods in Inner Mongolia and Mongolia. In order to answer this question, we review a series of studies done in Inner Mongolia and Mongolia, involving; field surveys, grazing experiments, stimulation modelling and farm demonstrations. Other papers in this panel session deal with additional issues influencing grasslands.

Climate and grassland types
The climate of Inner Mongolia and Mongolia, across the Mongolian Plateau and neighbouring areas, is continental and harsh with low precipitation from 50 to 500mm (mostly in summer), and cold and windy in winter. Plants start to grow when the daily mean air temperature is above 5°C in spring and cease when air temperatures decline below 5°C in autumn (Zhao et al., 2008; Jamsran et al., 2018).

In Inner Mongolia, from northeast to southwest annual precipitation decreases resulting in a
The gradual shift of vegetation from forest in the east to desert in the west. The grasslands range from meadow to typical to desert steppe. The meadow steppe is a humid type in the east with 320-380mm annual precipitation and black chestnut soil. The main plant species are the grasses Leymus chinensis, Stipa baicalensis, and the forb Filipilium sibiricum. The typical steppe grows on a chestnut soil, is the largest grassland type and covers much of the middle of Inner Mongolia. The annual precipitation is 310-350mm. The main species are the grasses Stipa krylovii, Stipa grandis, Cleistogenes squarrosa (C4) and the semi-shrub Artemisia frigida. The desert steppe, on brown chernozem soils, is close to desert in the west with 150-280mm annual precipitation. The main grass species are Stipa klemenzii, Stipa gobica, Stipa breviflora, Cleistogenes songorica (Zhao et al., 2008).

In Mongolia, a cold and humid climate and high mountain belt in the north gradually shifts to a warmer (in summer) drier climate and desert in the south. Zonal grasslands in Mongolia include mountain forest steppe, steppe, and desert steppe. The forest steppe is of 200-300mm annual precipitation and 130-150 days growing season. The main plant species are the grasses Festuca lenensis, Koeleria macrantha and Poa allenuata. The steppe is the largest grassland type in Mongolia with 200-250mm annual precipitation and 150-170 days growing season. The main plant species are the grasses Stipa krylovii, Stipa grandis, Cleistogenes squarrosa, and Leymus chinensis. The desert steppe is a unique type between steppe and desert with 100-125mm annual precipitation and 170-190 days growing season. The main plant species are Stipa gobica, Stipa glareosa, Cleistogenes songorica and Allium polyrrhizum, (Jamsran et al., 2018).

The climate and grassland types are very similar between Inner Mongolia and Mongolia. The grasslands in both countries have suffered from over grazing. Livestock numbers have quadrupled since the 1950’s in China and since 1990 doubled in Mongolia (Kemp, Han et al., 2020). With over-grazing, there is an initial shift from palatable to less-palatable plant species then a decline in productivity and in some areas to eventual desertification (Kemp, Li et al., 2020). With more people and more animals on the grassland, the challenge is to reduce stocking rates to sustainable levels where the grasslands can recover to more productive states and then be maintained at those better states. We need to understand the grassland livestock system to solve the problem of grassland degradation in terms of environmental and economic considerations.

Grassland health

From 2005 to 2007, sites were monitored in each of the meadow steppe, typical steppe, and desert steppe grasslands of Inner Mongolia. Vegetation, soil, hydrological properties, and methane emission of soil were measured to understand the grassland degradation stages every 2m along 3 * 50m transects from a watering point or stock yard within each grassland type. The grasslands were classified in four seral stages from early to late, applying the ecological concept of plant community succession; the reverse of succession then being degradation. The typical and desert steppe sites studied were in a lightly degraded stage, while the meadow steppe was heavily degraded (Zhao et al., 2008). This study showed that key indicator species such as the grasses: Leymus chinensis declined with degradation, Cleistogenes songorica was more frequent at intermediate stages, while Stipa grandis was more frequent in heavily degraded sites.

**Figure 1:** Total values of ecosystem services under different grazing intensities in the three types of steppes. Different uppercase letters indicate significant differences among grazing intensities in the same steppe

A survey of livestock grazing intensities across the meadow steppe, typical steppe, and desert steppe indicated that heavy grazing reduced plant community production, species richness and species asynchrony, which reduced temporal stability of plant community (Qin et al., 2019). Consequently, the total value of ecosystem services declined with increasing grazing intensity (Figure 1).

One of the more important environmental services from grassland is as a methane sink throughout
the growing season. Nil or light grazing on the desert steppe, resulted in more methane uptake into the soil than moderate or heavy grazing. Differences were less for the typical and meadow steppe, though the trends were similar (Tang et al., 2013). A further study on the typical steppe found that light to moderate grazing was optimal for methane uptake and for managing the plant species composition (Zhang et al., 2015). The biomass of Leymus chinensis was maintained above 70% and the less desirable Artemisia frigida below 10% when the stocking rate was half the district average.

Extensive surveys were done in 2014 and 2016 across all Mongolian grasslands to define their current health using 1450 survey sites (Densambuu et al., 2018). The grasslands in 2016 were: Class I, non-degraded state (42%); Class II, slightly degraded and may be recovered quickly (14%); Class III, moderately degraded and would take 5-10 years to recover (21%); Class IV, heavily degraded with local loss of key desirable plant species (13%); and Class V, fully degraded with extensive soil loss leading to desertification (10%). These results found that degradation had increased since 2014, with 10% less land in Class I and 5% more in Class V. Clearly there is a significant decline in grassland condition, though about half the grasslands were judged to achieve a sustainable state in ten years with better management. These overall averages suggest the grasslands are in better condition than in Inner Mongolia, but the distribution of results showed that in central Mongolia, the steppe near the capital Ulaanbaatar and other major towns, was in a poor condition. Mongolia allows common grazing anywhere in the country, which has meant more herders have moved closer to urban areas so that family members can receive better education and health services and/or find supplementary income. The higher density of herder households has reduced their ability to move to new grazing areas every few months. Herders used to move up to six times a year, now some do not move at all, or only twice a year.

**Desert steppe grazing management**

A long-term sheep grazing (only in summer) experiment (2004-15) with 4 stocking rates and 3 replicates, was done on a desert steppe site of Inner Mongolia to investigate the productivity and plant species diversity responses to grazing and climate variability. The high, district average, stocking rate decreased species richness, diversity, net primary productivity and per head animal production (Zhang et al., 2019, Wang et al., 2020). The grassland methane sink was reduced under moderate or high stocking rates in summer, but there was no treatment effect in winter (Wang et al., 2012). The light stocking rate that optimised environmental services was half the district average.

**Figure 2:** Trends in the interaction between shrub and perennial grass herbage mass in the desert steppe from 2004 to 2015 in response to grazing treatments. The starting point for all treatments in 2004 is identified with an oval. The dashed line indicates the 1:1 ratio of these two plant groups (from Wang et al., 2019).

The total grassland growth on desert steppe is only 1-1.5 t DM/ha/year. The optimal light stocking rate meant that the estimated consumption by sheep was only 10% of that herbage and the standing herbage mass over summer was above 0.5 t DM/ha. Studies on the typical steppe had shown the optimal consumption was 20%, but the minimal herbage mass that should be maintained was also 0.5 t DM/ha over summer (Zhang et al., 2015).

The dominant species in the desert steppe experiment were the low palatability grass, Stipa breviflora and the semi-shrub Artemisia frigida, indicating that the site was over-grazed and degraded. In general, the stocking rate treatments did not change the biomass of Stipa breviflora within each year, but did affect Artemisia frigida, indicating that the animal growth rates were dependent upon the shrub, not the grass (Wang et al., 2020). When the annual trends in biomass between these two species are compared (Figure 2) it is evident that the grass and shrub maintained close to a 1:1 ratio under light grazing for most years, whereas the moderate and high stocking rates had much higher proportions of unpalatable grass and little shrub. This experiment showed...
that it took eight years before the treatments differentiated significantly and the light grazing treatment had the same results as no grazing. Grazing bans have typically been for five years. Financial analyses showed that the light stocking rate had the highest net income per hectare.

Modelling and farm demonstrations

A series of models were developed (Kemp & Michalk 2011, Kemp 2020) in order to understand the grassland livestock system, including feed (energy) balance analyser (StageONE), linear program optimiser (StageTWO), dynamic sustainability (StageTHREE) and precision livestock management (PhaseONE). In general, these models showed that halving the average stocking rates would increase herder net income and improve the grassland condition. A large farm project was then established across the grasslands of Inner Mongolia to compare demonstration farms where stocking rates were reduced, while improving supplementary feeding in winter and better use of warm, shelter sheds, against control farms. The demonstration farms had higher net incomes than the controls, even where the overall stocking rate had been reduced to nearly half the district average (Kemp 2020). This study was short-term, but visually the grasslands were reported to be in better condition on the demonstration farms.

Conclusion

Overgrazing has caused grassland degradation in both Inner Mongolia and Mongolia. This has resulted from various National and Local policies that enabled / encouraged herders to increase their animal numbers, often with the view that this would increase household incomes. However, the results of grazing experiments, modelling and farm demonstrations have all consistently shown that the highest net income results from stocking rates that are around half that which applied in the early 2000’s. Net income is a better criterion than gross income as that indicates the disposable income for households.

The studies of grassland condition and environmental services show that stocking rates that are half the district averages have resulted in better outcomes for the grassland (Kemp 2020). However, herders who have used common grazing across large areas and where fences are not used, are unfamiliar with measuring and managing stocking rates. In addition, there are many aspects to environmental services and to manage each to an optimal level is effectively impossible for herders. The more important environmental services are though, all related to the herbage mass of the grassland and that is the component that herders can manage (Kemp, Li et al., 2020). A decline in herbage mass is often the first visible sign of degradation, less production, more soil erosion etc., and can be used to manage grasslands. Herders can be taught to identify the minimum critical values of herbage mass that should be maintained. Animals should be moved to new grazing areas when that critical value is approached. The experiments on the desert and typical steppe found that critical value was 0.5 t DM/ha. By managing on herbage mass criteria this reduces the need to define optimal stocking rates.

Acknowledgement

National Natural Science Foundation of China, Australian Centre for International Agricultural Research and Swiss Development Corporation funded this work.

References


Herders’ attitude and decision making in stocking rates and implication for grassland management in China

Li Ping¹, Zhi Rong¹, Jeff Bennett², Lin Kejian¹, Jin Ke¹

Institute of Grassland Research, Chinese Academy of Agricultural Sciences, Hohhot, 010010, China. Crawford School of Public Policy, Australian National University, Canberra, 0200, Australia.

Key words: over grazing, subsidies, penalties, choice modelling, policy

Abstract

Overgrazing is widely acknowledged to be the main driver of grassland degradation. Governments seeking to address the grassland degradation problem have therefore focused on policies designed to reduce overgrazing. The Chinese government has implemented a series of policies with the aim of protecting the grasslands from more serious degradation. The efficacy of these policies has been questioned given that, since their introduction, stocking rates have remained high in many affected areas. It has been suggested that the government should enhance grassland monitoring and the punishment of overgrazing. Increasing penalties would reduce stocking rates, however that is likely to cause more social and economic problems. A survey of 1588 herders found that 40% consider the government should set a grass-animal balance rule and implement it strictly, and 30% think the government should only recommend a grass-animal balance rule for herders to follow only 30% of herders were likely to set the stocking rate by themselves. An analysis of the survey data showed that household expenditure (food, house, clothing, medical expenses) was an important driver of overgrazing. Most herders depend upon their livestock for income; only 3% have a part-time job, compared to over 30% of all Chinese farmers. On average 70% of a herders’ income comes from livestock production and around 26% comes from subsidies. The contingent model developed found that, increasing subsidies with punishment for non-compliance, should reduce stocking rates and help maintain herders’ income, but not to the level required to alleviate poverty and unsustainable. We suggest that herders need training to improve their business skills so they can move from a focus on survival to one where optimising production and better marketing, are the aims of their livestock enterprise. Demonstration farms need to be part of this training.

Introduction

Grasslands cover about 40 percent of China’s land territory, and play important role in livestock production and ecological security. However, over 80% of China’s grassland degraded during last 100 years. Overgrazing is widely accepted to be the main driver of grassland degradation (Valle Junior et al., 2019; Herrero and Thornton, 2013; Liu et al., 2013). Thus, the Chinese government has implemented a series of policies with the aim of protecting the grasslands from more serious degradation. These policies have included the establishment of private ‘use rights’ over land, ‘return grazing to grassland project (tui mu huan cao)’, the ‘grain to green program (tui geng huan lin huan cao)’, the Beijing-Tianjin sand storm control program and the ‘grassland eco-subsidy and award policy’ (Robinson et al., 2017). The efficacy of these policies has been questioned given that, since their introduction, stocking rates have remained high in many affected areas (Li et al., 2017; Wang et al., 2016). Many researches have concluded that these policies failed to reduce stocking rates due to insufficient subsidy, monitor, enforcement and compliance (Wang et al., 2016; Chen et al., 2014; Yin, 2017). However little research has explored the reason why herders overgraze the grasslands and herders’ preferences are overlooked as well both in policy making and researches.

Materials and Methods

Herders’ preferences and policy effects on reducing stocking rates were analysed using choice modelling (Louviere and Woodworth, 1983) and contingent behaviour model (Martínez-Espiñeira et al., 2015), based on the face to face household survey that was carried out in Inner Mongolia, one
of the traditional grassland provinces in China. After 5 focus groups and a pilot survey involving 30 interviews, 5 policy attributes were selected as the choice experiment attributes: pension payments, loan period, the enforcement of policies, punishment for overgrazing, and subsidy payment (table 1). Herder respondents were also asked to state the number of sheep equivalents and the amount of land they rented in under their selected policy mix alternative. Using these contingent behaviour responses, and the answers to a question on the area of land currently accessed for grazing, herder stocking rates were calculated to form a dependent variable to be explained in a GLS regression model by the policies and a range of socio-economic variables.

Table 1: Policy attributes and levels

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Status quo</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pension (yuan/month)</td>
<td>300</td>
<td>600</td>
<td>900</td>
<td>1200</td>
</tr>
<tr>
<td>Loan period (year)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Enforcement (%)</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>Punishment (yuan/sheep)</td>
<td>100</td>
<td>200</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Subsidy</td>
<td>No conditions on payment, 2.5 yuan/mu</td>
<td>5 yuan per mu if complies with the grass animal balance rule otherwise no payment.</td>
<td>7.5 yuan per mu if complies with the grass animal balance rule otherwise no payment.</td>
<td>10 yuan per mu if complies with the grass animal balance rule otherwise no payment.</td>
</tr>
</tbody>
</table>

Stocking rates under all policy scenarios were then estimated from the GLS model, and a list of potential policy mixes were ordered in terms of the stocking rates they are predicted to induce. Taking the current stocking rate and what local ecologists think as acceptable stocking rates into account, threshold stocking rates were determined at 0.94, 0.61 and 1.39 sheep unit/ha in typical steppe, desert steppe and sandy steppe, respectively. Using these thresholds, the policy mixes that are capable of achieving sustainable stocking rates were analysed for their popularity among herders.

The utility of each policy mix was estimated from the choice model. This allows the policy mixes that achieve the threshold stocking rates to be ranked in terms of their utility. Given that the utility of the existing policy mix can also be estimated using the choice model, it is then possible to consider how alternative policy mixes compare, in terms of utility, against the status quo. Those policy mixes yielding herder utility levels greater than the status quo can be concluded to be more popular amongst herders than the current policy mix.

Herders’ attitudes in grassland rules are investigated online by Wechat App through China’s grassland region, covering all 13 provinces where the grassland eco-compensation policy has been implemented.

Results
Herders’ policy preferences

A conditional logit model of choice was used to estimate pastoralists’ preferences to policy choices (table 2). The result showed that the higher the pension payment and the longer the loan repayment period the more likely that herder respondents would choose an alternative policy mix. The greater the chance of being caught and the higher the penalty imposed for breaches, the less likely an alternative policy mix was chosen. The payment of an increased but conditional subsidy also increased a herder’s likelihood of choosing a new policy option. The contracted grassland area, rented grassland area, the hay production area, as well as herder age and education level showed significant influences on the respondent herders’ choices.
### Table 2: Estimated results of choice model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Conditional logit model with social-economic characters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
</tr>
<tr>
<td>Pension</td>
<td>0.001***</td>
</tr>
<tr>
<td>Loan</td>
<td>0.181***</td>
</tr>
<tr>
<td>Penalty</td>
<td>-0.001***</td>
</tr>
<tr>
<td>Enforcement</td>
<td>-0.014***</td>
</tr>
<tr>
<td>Payment</td>
<td>0.225***</td>
</tr>
<tr>
<td>asc</td>
<td>-2.162***</td>
</tr>
<tr>
<td>Contracted land</td>
<td>0.008***</td>
</tr>
<tr>
<td>Rented land</td>
<td>-0.001***</td>
</tr>
<tr>
<td>Grassland for hay production</td>
<td>0.003***</td>
</tr>
<tr>
<td>Age of respondents</td>
<td>0.028***</td>
</tr>
<tr>
<td>Desert Steppe</td>
<td>0.759***</td>
</tr>
<tr>
<td>Sandy Steppe</td>
<td>1.218***</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-1470.4826</td>
</tr>
<tr>
<td>Number of observations</td>
<td>5085</td>
</tr>
<tr>
<td>LR chi2(8)</td>
<td>783.33</td>
</tr>
<tr>
<td>Prob&gt; chi2</td>
<td>0.0000</td>
</tr>
<tr>
<td>Pseudo R2</td>
<td>0.2103</td>
</tr>
<tr>
<td>AIC(Akaike Information Criterion)</td>
<td>2964.965</td>
</tr>
<tr>
<td>BIC(Bayesian Information Criterion)</td>
<td>3043.374</td>
</tr>
</tbody>
</table>

### Stocking rates under different policy scenarios

From table 3 we can see, the policy variables used as independent variables all have negative coefficients (i.e. increases in the policy attributes cause expected stocking rates to fall). However, only pension, punishment and enforcement have statistically significant effects on stocking rate: increased pension payments and/or punishment for exceeding stocking rates and/or probability of being caught will cause stocking rates to fall. In contrast, the existing policies (loans and subsidies) have no significant impact on the herders’ desired stocking rates.

### Table 3: Stocking rate as a function of policy variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pension (1000CNY/month)</td>
<td>-0.106***</td>
<td>0.034</td>
</tr>
<tr>
<td>Loan (years)</td>
<td>-0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>Enforcement (% probability)</td>
<td>-0.002***</td>
<td>0.001</td>
</tr>
<tr>
<td>Punishment (1000CNY / excess sheep)</td>
<td>-0.164***</td>
<td>0.058</td>
</tr>
<tr>
<td>Payment (1000CNY / mu)</td>
<td>-5.531</td>
<td>4.370</td>
</tr>
<tr>
<td>Constant</td>
<td>1.184***</td>
<td>0.100</td>
</tr>
<tr>
<td>Socio-economic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contracted area (100 ha)</td>
<td>-0.031***</td>
<td>0.004</td>
</tr>
</tbody>
</table>
### Ranking policies by stocking rates and popularity

Different mixes of policy measures have different effects on stocking rates in the three different regions of Inner Mongolia. Furthermore, the three different regions have different ‘threshold’ stocking rates. It was found that 995 of the possible policy mixes could achieve the threshold stocking rate in the typical steppe region while 48 could achieve the goal in the sandy steppe region and only 29 policy combinations reached the targeted 30% reduction in stocking rates for the desert steppe region. The 29 policy mixes that are predicted to achieve the threshold, sustainable stocking rates throughout the three grassland ecosystem types in Inner Mongolia are selected for popularity analysis.

The herder utilities of these 29 policy mixes ranged from 3.16 to 5.49 compared to the average herder utility produced by the status quo policy mix of 5.4. Of the 29 policy mixes only two provided herders with as average utility greater than that currently being enjoyed. Which indicated that only two possible policy mixes would, on average, make herders better off and achieve the required ecological condition of the grasslands.

The two policy mixes that achieve the dual goals of improved herder well-being and improved grassland condition (to the desired threshold level across all ecological regions) involve a combination of penalties and rewards. Specifically, in terms of rewards the pension payment would rise (under both policy mixes) from 300 yuan to 1200-yuan, loan repayments would be repaid after five years not one and the subsidy would rise from 2.5 yuan to 10 yuan. Penalties would also increase. The chance of being caught exceeding the legal stocking rates would have to rise (from 10 per cent) to a minimum of 50 per cent and the associated penalty would rise to 600 yuan (from 100 yuan). Alternatively, more effort could be allocated to enforcement to ensure a 70 per cent rate of detection and the penalty would need to rise to 400 yuan.

### Herders’ attitudes on grass-animal balance rules

The grass-animal balance rule is written in China’s grassland law, which says that herders should adjust their animal group according to grassland condition. Usually local governments set sustainable stocking rates based on grassland production and herders then can calculate how many animals they can raise based on their grassland areas and the stocking rate. With the low compliance of grass-animal balance rule, we have expected herders might dislike this rule and reject this rule. However, the survey data show that 40% of the respondents consider the government should set the grass-animal balance rule and implement it strictly, and 30% think the government should only recommend a grass-animal balance rule for herders to follow, only 30% of herders were likely to set the stocking rate by themselves. This indicates that 70% of herders think this grass-animal balance rule is necessary, so that they wouldn’t intended to violate the rule.

### Discussion

As expected, both the punishment and penalty attributes included as policy options in this study have been shown to have significant influences on herders’ choices and their stocking rate intentions. Respondent herders were shown to dislike policies with higher probabilities of being caught in breach of stocking rate rules and higher penalties for such breaches. In the CB for policy alternatives with these characteristics, the sampled herders indicated that they would lower their stocking rates.
While overgrazing is widespread in grassland, this study found that most herders do not intend to violate the However, grass-animal balance rule indicated that the incentives behind overgrazing are worth deep thinking considering the validity of grassland protecting policies. The survey shows that herders have less external income sources compared with farmers. Only 3% of the respondents have other job incomes compared to the general situation where about 30% of Chinese farmers have other part time job incomes. The high dependence of household income on livestock production makes it very difficult, or even impossible for some cases, to reduce stocking rate without a subsidy. The key finding is that best policy combination to improve grassland condition while protecting pastoralists welfare, is to increase the subsidy level and enhancing penalties. As the sustainable development of herders’ livelihoods is important, more effort is needed to increase herders’ income resources as well as productivity.

References


Implications of herder attitudes for stocking rates in China and Mongolia

Yin Yanting1, Li Ping1, David Kemp2

1 Institute for Grassland Research, Chinese Academy of Agricultural Science, Hohhot, Inner Mongolia Autonomous Region, China; 2 Graham Centre for Agricultural Innovation, Charles Sturt University, Orange NSW Australia

Key words: herder attitudes; herder styles; desired stocking rates; policy

Abstract
Over-grazing of the grasslands in China and Mongolia is a common problem. Herders typically aim to increase their animal numbers to then hopefully, improve their status and incomes. Various studies have shown that stocking rates often need to be halved to restore grasslands to a sustainable state. Governments have been enacting policies to achieve a reduction in stocking rates, especially in China. However, in both countries, herders have freedom to set their own stocking rates. A survey was done of ~900 herders in Inner Mongolia, on the five main grassland types, to define their styles, attitudes and intentions for stocking rates, their desired stocking rates and how that related to actual and recommended stocking rates and the implications for policies designed to rehabilitate degraded grasslands. Most herders only provide minimal inputs to livestock relying primarily on grasslands for fodder. Herders were grouped into four main types, those who intended to increase or decrease stocking rates Vs their actual stocking rates as a function of their desired stocking rates (+/-). They varied from those who had less than their desired stocking rates yet intended to reduce them further, to those who had more than their desired stocking rates and were intending to increase them. There was a general relationship within villages between the ratio of desired to actual stocking rates and actual number of animals held by the household. This general relationship indicated that within a village the herder’s actual ‘desire’ was for a specified number of animals, rather than a specified stocking rate. Similar attitudes prevail in Mongolia where herders do not think about animals per hectare. The policy implications are discussed.

Introduction
China has approximately 400m ha of grasslands and Mongolia 128m ha. In China 90% of these lands are considered degraded to varying degrees (Kemp & Michalk 2011) while in Mongolia degraded grasslands are mainly in central regions around the capital and large towns (Densambuu et al., 2018). Historically, common grazing has been practised for millennia. Since 1949, China has implemented major changes in grassland management practices. In the 1980’s there has been a progressive implementation of policies that allocate land to individual households where herders chose the stock numbers they consider the land will sustain within a limit set by local officials. In Mongolia, individual herders still graze lands in common and decide how many animals they wish to have. The problem now is that the number of animals grazing the grasslands has been shown to often be twice or more, that which would sustain the grasslands (Kemp 2020). Over-grazing has been a major problem since the 1980’s in China and since 1990 in Mongolia. The Governments of China and Mongolia have a priority to improve the grasslands as a prime national resource, while alleviating poverty among herder households. Various policies in both countries have been designed to achieve sustainable grazing practices. However, compliance with these policies has been variable. Herders can have different attitudes about how many animals the grassland could sustain, compared to the views of researchers and officials. This paper reports on a survey of herders in Inner Mongolia to evaluate their styles (Kemp & Michalk 2011) attitudes and intentions for stocking rates and the implications for policies designed to rehabilitate grasslands (see Hou et al., 2020 for more details). Many of the herders in Inner Mongolia are Mongolian with a similar background to those in Mongolia. The work done in Inner Mongolia provides some insight into the possible attitudes of Mongolian herders. Future work will resolve the similarities and differences.
**Materials and Methods**

The survey of herder attitudes was done in Inner Mongolia, across the five main grassland types, all of which also occur in Mongolia. Annual precipitation varies from 200-500mm, mostly falling during the growing season from May to September. The average annual temperature is close to 0°C, with minimums in winter well below -20°C. An initial survey was done in 2010 (180 households), followed by a large sample in 2012 (combined total of 909 households). The two surveys included structured questions in five topic areas: (1) the socioeconomic characteristics of the herders and their households; (2) opinions about overstocking, carrying capacity, and the degradation of their rangelands; (3) information about the herders’ present management practices (including their actual stocking rates and their desired stocking rate); (4) attitudes towards new agriculture practices; and (5) attitudes towards the “balancing animals and grass” policy. Most questions were semi-structured, rather than open-ended.

**Results**

Across the five grassland types in Inner Mongolia, the average family size (4) and household labour (2) were similar, but the number of animals managed varied considerably, as did the area of grassland per household. The households from the meadow steppe region had the largest number of livestock (661 sheep equivalents, SE) highest stocking rates (3.2 SE/ha) but lowest net livestock income/SE (118 yuan/SE). In contrast, the households in the desert steppe region had the largest areas of grasslands (963 ha) the lowest stocking rates (0.6 SE/ha) and a higher net income/SE (198 yuan/SE). The total livestock income was greatest (126,796 yuan) for households from the typical steppe region and they also had a high net livestock income/SE (245 yuan/SE). Households in the sandy steppe region had the least animals, the lowest total livestock income (57,745 yuan) but the lowest livestock cost/SE (33 yuan/SE), which resulted in a similar high net livestock income/SE (246 yuan/SE) as in the typical steppe. In the sandy steppe, herders had some irrigation to grow forage, more so than in other regions, which resulted in a higher stocking rate than in the desert steppe where precipitation is similar. The considerable variation in total livestock income/SE reflects the current state of markets across grassland areas and the variability in amount of animal product per SE.

![Relationship between income and costs per sheep equivalent, for five grassland regions, surveyed in 2010. Data are the limits for probability classes (Hou et al., 2020). A conceptual framework was used to help understand herder styles and from that their attitudes. Their styles can in part be characterised by how the animals are managed and fed through the year. The transitional framework for herders in East Africa, developed by Neidhardt et al., (1996) of user / keeper / producer / breeder is similar to what has been evident among herders in China. To test this framework the total income across farms was related to the total expenditure on fodder (Figure 1). We assumed that herders who spent little on fodder would be the more traditional keeper, while those who spent more money on fodder were behaving more as producers. It is evident that most herders were spending much less on fodder than their livestock income. The main exception was one group on the sandy steppe who had the highest income and about the same costs per SE. In Mongolia, most herders would be keepers.](Image)

The actual stocking rate (ASR) used by herders would be influenced by several factors, such as seasons, markets, state of the grassland, finances, social factors and Government policies. All these components would feed into the herders desired stocking rate (DSR) (Hou et al., 2013). We then examined the relationship between a herders stocking rate intentions (to increase or decrease stocking rates) Vs the difference between the desired and actual stocking rates (Figure 2). This classified households into five groups from those who had more animals than desired yet were still going to increase them (18%), to those that had less than desired, but intended to decrease their stocking rates (26%). These apparent contradictions were evident in the survey results. It was not clear what factors were then driving these decisions.

The mean responses for the four main groups
identified in Figure 2 within each County, where then examined in relation to total household animal number and the difference between desired and actual stocking rates ((DSR-ASR)/ASR (%), Figure 3). There was a consistent negative relationship between the difference in stocking rates and the total animal number per household across three groups in all counties. Group 2 herders (red symbols) wanted to increase animals, while group 3 herders (blue symbols) wanted to decrease them – it suggests that would align along a common relationship as the group 2 herders had less animals than group 3. These groups for Sunite and Xilinhote were not significantly different and the fitted regression was not significantly different for the group 1 herders who said their intent was to decrease animals, even though their DSR was greater than their ASR – the hypothesis presented here suggests they may in effect chose the county trend and increase their animal number. The fitted regression for Sunite and Xilinhote suggests that herders aim for a flock size of about 450 SE, at which their DSR and ASR would be the same. Similarly, for the Xinbaerhu herder groups 1, 2 & 3, they aligned on a common relationship suggesting that they would settle on 600 SE where their DSR and ASR would align.

The group 4 herders did not conform to the same pattern as other groups. In general, this group intended to increase their animal number, but were maybe constrained, because that would mean stocking rates more than what is considered desirable in those counties. Their actual animal numbers were only 14-17% less than the estimated ideal village animal number, which may mean a less-strong desire to increase them.

In Mongolia similar surveys have not yet been done, but anecdotally there is the opinion that herders would like to have at least 1000 SE. This reflects the poorer market prices in Mongolia, compared to Inner Mongolia and Government policies that have encouraged herders to increase their animal number.

Discussion
The grasslands of China and Mongolia are widely acknowledged as being overgrazed and the policy goal is to reduce stocking rates to a sustainable level (Kemp 2020). In Inner Mongolia, various studies have all shown that a 50% reduction in stocking rates is the required average change. In Mongolia, a similar level of reduction is required, though in this case that varies with region. However, herders often believe that more animals mean more income for them, even if the grassland condition would suggest otherwise. Defining what is sustainable does depend upon the general attitudes of herders.

The model for East African herders (Neidhardt et al., 1996) of user – keeper – producer – breeder as the development pathway, is similar to what applies among herders in both China and Mongolia. Most herders would fit within the keeper stage as their inputs to livestock are minimal and their animals depend almost
exclusively on seasonal conditions. Their focus is generally upon how many animals can survive through the year, rather than the producer model where the focus is more on the output of saleable products (meat, milk, fibre). In addition, herders do consider they need a certain number of animals to be regarded as a genuine herder (Figure 3). The dilemma now is that more herders wish to sell more animal products in order to improve their livelihoods and obtain services from society (education, health, phones, TV, vehicles, goods). That means they are transitioning to a producer model. To be producers you need to allow more forage per animal, which requires lower stocking rates. In Inner Mongolia where herders are allocated individual areas of land and now also rent land from their neighbours, it is evident that once they achieve their desired number of animals, the effective average stocking rate declines (Li et al., 2020, Li & Bennett, 2019) though the rented land now tends to be over-grazed relative to the herders own land. In China, policies need to allow for this mechanism to operate more effectively i.e. increase the available land per herder to a level that would naturally allow lower stocking rates. In Mongolia, there is a trend for herders to move into towns and cities, but they often still retain their livestock and ask other herders to manage them. Policies are being discussed that could involve a livestock tax to then discourage animal numbers above some set value.

Acknowledgements
This collaborative work was supported by the Chinese Government and the Australian Centre for International Agricultural Research.

References


Modelling the long-term impact on herder incomes and environmental services in an uncertain world

Behrendt, K.1,2; Kemp, D.R.1; Udval, G.3; Jargalsaihan, G.3; Han, G.D.4; Li Z.G.4; Li, P.5; Lkhagvaa, D.6

*1Graham Centre for Agricultural Innovation, Charles Sturt University, Orange, NSW, Australia; 2Harper Adams University, Newport, Shropshire, England; 3Research Institute for Animal Husbandry, Ulaanbaatar, Mongolia; 4Inner Mongolia Agricultural University, Hohhot, Inner Mongolia Autonomous Region, China; 5Institute for Grassland Research, Chinese Academy of Agricultural Science, Hohhot, Inner Mongolia Autonomous Region, China; 6Mongolian University of Life Sciences, Ulaanbaatar, Mongolia.

Key words: China; Mongolia; grassland; bioeconomic modelling

Abstract
Environmental, market and political influences affect herders’ livelihoods with the expectation that they maintain biologically and economically resilient systems. To balance these external influences and the trade-offs within a grassland system it involves the consideration of interactions between grassland ecology, technology use, environmental externalities, utilisation by grazing animals for food and fibre production, and the long-term profitability of the farming system. Many of these variables are slow-moving and are trade-offs are most efficiently studied with models. The StageTHREE Sustainable Grasslands Model, which utilizes the core functions and dynamics of more mechanistic tools, has been designed to minimize the skill and data required for parameterisation. It allows the key dynamics of the grassland systems to be incorporated along with the stochasticity of the system, in terms of both the uncertainty of the production and market environment. This enables an investigation into the sustainability and environmental impacts of alternative livestock management practices, so that these can be evaluated in relation to policy options. This paper presents an insight into the integration of herder level bioeconomic modelling for the analysis of grassland policy impacts in Mongolia and China. The research highlights that policy settings that reduce stocking rates can improve the environmental services from grasslands, and in most cases, also improve herder livelihoods and resilience.

Introduction
The management of grasslands is of critical importance to the livelihoods of over 5m low income herding households and ruminant livestock production derived from 520m hectares across the northern steppes of China and Mongolia (Kemp et al., 2020). Under ongoing grassland degradation with concurrent increases in livestock numbers and stocking rates, existing and new grassland policies are being considered to better meet the objectives of concurrently improving herders’ livelihoods while maintaining biologically and economically resilient systems (Brown et al., 2021). However, herders as the agents of change in the management of grasslands are influenced by a variety of interacting social, economic and environmental pressures (Addison et al., 2020). For both herders and policy designers to consider and balance the trade-offs of these influences within a grassland system involves the consideration of complex interactions between grassland ecology, technology use, environmental externalities, utilisation of the grassland resource by grazing animals for food and fibre production, and the profitability of the herder systems over the longer term (Behrendt et al., 2020b). The aim of this paper is to introduce the use of bioeconomic modelling of herder level grassland systems in both Mongolia and China to inform the analysis of different grassland policy options. The bioeconomic modelling enables the identification of the expected relationships between the
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

soils, grasslands, livestock, other physical and typical herder's resources are defined (including simulation period. For each case study region the 2012-2018; Mongolia: 2011-2020) over a 10-year (based on region specific market data; China: distributed) and normally distributed output prices weather station data; years are uniformly data over 2006-2019 (using nearest representative data). The simulations stochastically utilise daily climate approach can be found in Behrendt detailed description of the model and modelling developed using Matlab (Mathworks 2019) and a expert opinion. The are validated using published literature and secondary data and expert opinion. Model outputs outcomes. The models are calibrated using local experimental/field data, literature, case studies, secondary data and expert opinion. Model outputs are validated using published literature and expert opinion. The StageTHREE Sustainable Grasslands Model (SGM), which utilizes the core functions and dynamics of more mechanistic tools, such as the GrazPlan suite (Donnelly et al., 1997) and SGS Grassland Model (Johnson et al., 2003) has been designed to minimize the skill and data required for parameterisation. It considers both output price (sheep/goat meat and wool/cashmere) and climatic uncertainty in their effect on herder production, economics and environmental outcomes. The models are calibrated using local experimental/field data, literature, case studies, secondary data and expert opinion. Model outputs are validated using published literature and expert opinion. The StageTHREE SGM has been developed using Matlab (Mathworks 2019) and a detailed description of the model and modelling approach can be found in Behrendt et al., (2020a).

The simulations stochastically utilise daily climate data over 2006-2019 (using nearest representative weather station data; years are uniformly distributed) and normally distributed output prices (based on region specific market data; China: 2012-2018; Mongolia: 2011-2020) over a 10-year simulation period. For each case study region the typical herder’s resources are defined (including soils, grasslands, livestock, other physical and financial capital); current management practice and stocking rate as the initial state of the system. Initial stocking rates use standard Sheep Equivalent (SE) ratings for different animal types and are based on the average stocking rate for 2015-2019 at the soum level for Mongolia (due to commons rangelands grazing) and herder level for China (based on survey results).

A series of incremental reductions or increases from the initial stocking rate are then applied and modelled within each system using Monte Carlo simulation procedures with 250 iterations per stocking rate level tested. Daily, annual and cumulative changes in the state of soil, grassland and livestock resources and productivity are predicted. The benefits or costs of a herder transitioning to a new target stocking rate in response to a policy is embedded into the herder’s household economics (reported as Net Present Value as an annuity and its variability). Expected response curves are fitted to key final year simulation outputs to indicate the relationship between stocking rate and the impact on expected resource, production, economic and risk outcomes.

Materials and Methods
The two case study regions within Mongolia are the Khashaat soum (Arkhangai aimag) and Altanbulag soum (Tuv aimag) both located within steppe grasslands to the south and west of Ulaanbaatar. In the Inner Mongolia Autonomous Region of China, the case studies cover three biomes, namely the desert, typical and sandy steppes. The grasslands and their management within these regions vary with details provided by Han et al., (2021) and Kemp et al., (2020). This study uses a typical farm approach to define and model the herder systems within each grassland case study region.

The StageTHREE Sustainable Grasslands Model (SGM), which utilizes the core functions and dynamics of more mechanistic tools, such as the GrazPlan suite (Donnelly et al., 1997) and SGS Grassland Model (Johnson et al., 2003) has been designed to minimize the skill and data required for parameterisation. It considers both output price (sheep/goat meat and wool/cashmere) and climatic uncertainty in their effect on herder production, economics and environmental outcomes. The models are calibrated using experimental/field data, literature, case studies, secondary data and expert opinion. Model outputs are validated using published literature and expert opinion. The StageTHREE SGM has been developed using Matlab (Mathworks 2019) and a detailed description of the model and modelling approach can be found in Behrendt et al., (2020a).

The simulations stochastically utilise daily climate data over 2006-2019 (using nearest representative weather station data; years are uniformly distributed) and normally distributed output prices (based on region specific market data; China: 2012-2018; Mongolia: 2011-2020) over a 10-year simulation period. For each case study region the typical herder’s resources are defined (including soils, grasslands, livestock, other physical and financial capital); current management practice and stocking rate as the initial state of the system. Initial stocking rates use standard Sheep Equivalent (SE) ratings for different animal types and are based on the average stocking rate for 2015-2019 at the soum level for Mongolia (due to commons rangelands grazing) and herder level for China (based on survey results).

A series of incremental reductions or increases from the initial stocking rate are then applied and modelled within each system using Monte Carlo simulation procedures with 250 iterations per stocking rate level tested. Daily, annual and cumulative changes in the state of soil, grassland and livestock resources and productivity are predicted. The benefits or costs of a herder transitioning to a new target stocking rate in response to a policy is embedded into the herder’s household economics (reported as Net Present Value as an annuity and its variability). Expected response curves are fitted to key final year simulation outputs to indicate the relationship between stocking rate and the impact on expected resource, production, economic and risk outcomes.

Results and Discussion
The biophysical outputs shown in Figures 1 and 2 are centred on the final year of the simulation period, being the expected outcomes 10 years post-policy and associated change in stocking rate or flock size. In Mongolia responses are depicted against different herder flock scales (based on SE) with typical systems modelled to maintain the expected mix of sheep and cashmere goats. In China responses are shown with stocking rate as the independent variable for a single sheep enterprise as this was the predominant livestock type in the region.

Mongolia
As herders in Mongolia seasonally shift between different grazing areas the scale response curves indicate the mean weighted biophysical outcomes of all grazing areas, and notably there was found to be some differences between the seasonal grazing areas. As expected, with increases in the number of animals (i.e. total SE) being run by herders, the biophysical and environmental conditions deteriorate (Figure 1). Notably there is little expected change in the number of soil erosion emission events or total amount of soil loss during wind erosion (data not shown) in response to changes in flock scale (differences in soil erosivity and wind speed between soums influences absolute levels of wind erosion).
The reason for this is due to the overwhelming influence of abiotic factors and the fact, that even with complete grazing rest, it would take many years for ground cover and biomass to increase to a level that would enable a reduction in the influence of physical processes driving wind induced soil erosion, which is consistent with other studies (Jamiyansharav et al., 2018).

For indicators of grassland condition such as fractional ground cover, biomass and grassland canopy height, they notably improve with reducing herder scale, although there is a large amount of variation around the reported means (expected responses only shown for July as this corresponds to the predominant reporting period of grassland condition, although this may not be the maximums for the whole growing season). Animal grazing does influence these outcomes, as generally the animals are in low-moderate condition, and exhibit compensatory growth during the summer. As such, any reduction in stocking rate tends to enable animals to increase their grassland consumption per head (and for longer into the year) and maintain higher body weights, selling weights and reproductive rates. This leads to significant increases in grassland consumption, and some suppression of the expected response in grassland condition to any reductions in grazing pressure.

The observed differences between the soums are due to a combination of lower rainfall and a more variable climate at Altanbulag when compared to Khashaat, and the higher stocking rates at Khashaat. Although Altanbulag herders are expected to maintain higher household incomes due to receiving slightly higher meat prices and lower costs for some inputs due to their closer proximity to Ulaanbaatar, they face higher financial risk and herders in both soums gain a net economic benefit from reducing stocking rates.

**Figure 1:** Relationships between the sheep equivalents kept by herders in the Khashaat (-) and Altanbulag (--) soums of Mongolia and a range of biophysical and economic outcomes. Arrows indicate approximate position of herders’ current management practice within each soum.
**Inner Mongolia, China**

Similar relationships are observed across the three biomes in Inner Mongolia (Figure 2). Across all three biomes grassland condition is expected to improve with reducing stocking rates. Similarly, there are no notable changes in the number of dust emission events or quantity of dust emitted in response to stocking rate reductions (again here, soil erosivity and climate influence absolute differences between biomes). Also, as for Mongolia, there is a significant decline in the level of greenhouse gas emissions with reducing stocking rates.

Notably the tested stocking rate range within the desert steppe case study area is smaller than the others due to herders within this region reducing their stocking rates over the past decade in response to successful research, farm demonstrations and knowledge exchange programs. The consequences of the current management practice of herders in the desert steppe (in regards to their stocking rates) are that any policy settings that encourage herders to respond by further reducing stocking rates will have different effects on herders here than in the typical and sandy steppes. For both herders in the typical and sandy steppes they can reduce stocking rates and be expected to increase their livelihoods and resilience. This is consistent with the established general relationships between stocking rates on green grassland and animal production per head and per hectare (Kemp *et al.*, 2020), and subsequent system profitability (Behrendt *et al.*, 2020a). However, desert steppe herders will be forced to trade-off livelihoods against delivering environmental services to society (Behrendt *et al.*, 2020b).

The expected response curves developed through this modelling enables the prediction of both the economic and environmental consequences of likely responses in herder behaviour with regard to their scale and stocking rate. The modelling enables the identification of trade-offs between production, environmental and economic outcomes under uncertainty, which cannot be done cost-effectively and in a timely manner through field-based research or ex-post analysis. These ex-ante analysis help to understand and identify policies that better meet with the objectives of improving grassland condition, minimising negative externalities and improve herder livelihoods (Brown *et al.*, 2021).

**Figure 1:** Relationships between stocking rate in the Desert steppe (---), Typical steppe (----) and Sandy...
steppe (⋯) of Inner Mongolia and a range of biophysical and economic outcomes across a simulated range of stocking rates. Arrows indicate approximate position of herders’ current management practice within each biome.

References


THEME 7. CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS

Topic: Accelerating the use of Participatory Action Research for Development in Pastoral Lands: Challenges and Opportunities
Co-produced research supports pastoralists to pursue transformative social and ecological change in rangelands

Reid, R.S.1, Kassam, K.A S.2; Pickering, T. 1; Yasin, A.3; Jamsranjav, C.1, Jamiyansharav, K.1, Ulambayar, T.4 and Knapp, C.N.5

1Colorado State University; 2Cornell University; 3Samburu Youth Education Fund, Kenya; 4Zoological Society of London; 5University of Wyoming

Key words: co-production, rangeland partnerships, transformations

Abstract
Over the last two decades, pastoralists and researchers have formed powerful alliances to transform how we think about and do research-with-action in rangelands. These alliances promote faster learning about problems and their potential solutions by bringing together diverse partners and their different ways of understanding important issues. They also ensure research is fully relevant to real problems, so it supports pastoralists to act on both old and new issues that they face. While these approaches can be contentious when perspectives and experiences do not align, team members are finding them transformative, if they commit to working together over the long term.

Based on a long history of participatory research approaches in the social sciences, these alliances are now inter- and trans-disciplinary, spread throughout the sciences. This paper uses six case studies to explore the experience of teams who have used this research-with-action approach in the rangelands of Kenya, Tanzania, Mongolia, Tajikistan, Afghanistan, Spain and the US. These teams developed and implemented this approach not in halls of academia, but in equal pastoralist-researcher partnerships by creating full co-learning and democratized processes together. These teams then purposely built the capacity of all stakeholders to act together to promote desired change. The case studies integrate diverse knowledges at multiple scales into collective ‘learning and doing’ teams composed of pastoral peoples, policy makers, scientists, business people, and others. This process ensures a broad range of understandings and interpretations form the foundation of the actions and adaptations taken by actors across landscapes and scales. The approach contributes to the resilience of place-based social-ecological systems in rangelands by avoiding top-down, one-size-fits-all approaches. Uniting these ideas and practices has allowed research-with-action to become truly transformative, by accelerating the capacity of all stakeholders to learn and act more effectively.

Introduction
Many scholars say today’s sustainability challenges are sufficiently large that they will only be solved with transformational change, or rapid leaps to a new normal (Moore et al., 2014). Here, a ‘transformation’ is a fundamental change in the purpose, function or structure of our ecological, economic, or social systems (Walker et al., 2004).

In rangelands, pastoralists and researchers are experimenting with long-term partnerships, meant to transform science so it fully supports pastoral needs. In the process, these alliances create ‘face-to-face’ democracy, transforming the participants (Brick, Snow, and Van de Wetering 2001). For example, the Blackfoot Challenge and the Malpai Borderlands are two rancher-led partnerships in the US that formed, in part, to slow the fragmentation of open, rural landscapes (Wilson, Bradley, and Neudecker 2017; McDonald 2002). In Africa and Asia, these initiatives are part of community-based rangeland management (Reid, Fernández-Giménez, and Galvin 2014) or, more broadly, community conservation initiatives.

The objective of this paper is to describe how these partnerships work and briefly describe some of their outcomes and impacts, largely based on ideas and cases in (Knapp et al., 2019; Reid et al., in press).
Materials and Methods
This paper is a summary of an in-depth review of 4 long-term and 2 short-term case studies in Kenya, Tanzania, Tajikistan, Afghanistan, Mongolia, Spain and the US from (Reid et al., in press). The Tajikistan/ Afghani partnership worked in the Pamir Mountains to co-generate knowledge and create useful outcomes to help communities to secure their livelihoods and food systems (Kassam et al., 2018). The Mongolian case assessed the social and ecological impacts of community-based rangeland management (Ulambayar et al., 2017; Fernández-Giménez, Allegretti, et al., 2019). The Kenyan / Tanzanian case studies focused on drought in Samburu (Reid et al., in press) and balancing wildlife conservation and pastoral development in the cross-border region of Maasailand (Reid et al., 2016). The Spanish case study looked at the role of women in Spanish pastoralism (Fernández-Giménez, Oteros-Rozas, and Ravera 2019). The US case focused on a ranch-scale participatory grazing experiment to test different grazing practices that would allow ranchers to sustain the land for future generations (Fernández-Giménez, Augustine, et al., 2019; Wilmer et al., 2018).

Results
We decided to call this type of science, ‘transformative science with society’ (TSWS) because the approach goes well beyond what is called ‘transdisciplinary science’ (see Reid, et al in press for more details). These are then TSWS partnerships. Most of these partnerships aim to transform pastoral systems in a positive way, but they also focus on transforming how scientists work with pastoral peoples. They do this by ensuring that science is driven by the needs of pastoral people and their rangelands.

We found seven processes that form the foundation of the partnerships (Reid et al., in press). First, these partnerships build collaborative relationships (1) that establish trust, build support for project outcomes, empower less powerful voices, and create a way to convene partners around a central problem. These partnerships then use co-production (2) ‘that iteratively brings together diverse groups and their ways of knowing and acting to create new knowledge and practices to transform societal outcomes’ (Wyborn et al., 2019):322. Partnerships then usually integrate different knowledges (like Indigenous, practitioner and scientific, 3) and create a robust practice of social learning (4), where the partnership experiments together, adapts and experiments again. The partnership also focuses on capacity building (5) to ensure participants develop and refine their leadership and partnering skills. Particularly in our East African and Mongolian cases, we found capacity building critical to long-term impacts on policy and practice. Most partnerships did deep networking (6) both within and outside the partnership. These partnerships also implemented action (7), like changing a management practice, restoring land, and helping to design policy and practice that lead directly to action.

Discussion
What kinds of outcomes and impacts did these partnerships have? We define outcomes as changes in knowledge, skills, attitudes and relationships that cause changes in behaviour of the partnership’s clients or the environment, and impacts as longer-term effects of the partnership’s outcomes on society and the environment (Belcher et al., 2019).

Partnership outcomes were abundant and diverse (Reid et al., in press). All the partnerships achieved the outcome of stronger trust and relationships, more inclusion and respect and empowered pastoral voices. Some of them changed the way the wider society talked about pastoralism, by, for example, debunking the tragedy of the commons narrative. The East Africa, Tajikistan/Afghanistan and US cases changed the way government and NGOs valued pastoral knowledge, leading to more inclusive projects that jointly identified problems and needed action together. In the US case, it was clear that all team members and ranchers made shifts in their mental models of how rangelands and communities work, opening the door to new concepts and solutions. Partnership capacity building efforts propelled pastoral community members to leadership positions. One of the pastoralists on the East Africa team described how the research allowed them to see problems from many different angles, a character seen as very useful by their communities (Reid et al., 2014).

Some of the larger impacts of these partnerships were more intangible, ‘sometimes occurring faster than expected and stretching far into the future’ (Reid et al., in press). Faster than expected impacts occurred in Kassam’s work, where maps co-generated in one community were used to establish their land tenure and stop a gold mine (Kassam 2009). In Maasailand, the partnership co-developed a land-use map that the community used to slow down rapid conversion of pastoral
land into an urban development (Reid et al., 2016).

And can these outcomes and impacts be called transformative? In the Tajikistan and Afghanistan case, the lead scientist was able to have strong input into the new Afghani climate policy, precisely because he had worked closely with Afghani communities. In East Africa, it appears that the research may have helped catalyze and accelerate transformations already in process. Here, pastoral community leaders and researchers were invited ‘to participate in task forces to develop the new Wildlife Act associated with the new Kenyan constitution. The task force was able to put into place fundamental changes that now allow pastoral communities to lead and manage community conservancies for the benefit of pastoral livelihoods and wildlife conservation for the first time’ (Reid et al in press). In several cases, it is clear that one of the most transformative processes was capacity building, where decades later pastoral participants partially credit the partnership with their success in becoming major leaders who now make substantial change in their communities (Reid et al., 2014).

In all partnerships, the researchers transformed the way they do their science, which many described as a permanent change. Here, they now find it impossible to do top-down science that creates conclusion without input from the pastoral community. Many are very committed to the process of co-generation of knowledge, with respectful blending of different knowledges.

These partnerships face recurring challenges for both scientists and pastoralists (Reid et al in press). They are complex and require significant time commitments. There is often hidden bias on the parts of scientists (particularly biophysical scientists) which must be recognized and mitigated. And finally, it is possible for a partnership to have unintended negative consequences. This can occur, for example, if the partnership inadvertently strengthens existing oppressive power structures.

Finally, we identified some needed change in these partnerships and the science they do for the future. First, there needs to be more attention to power dynamics in these partnerships. Partnerships need to pay close attention to the dominate western European cultural narrative and attempt to decolonize this science more fully, welcoming Indigenous science and ways of knowing. And lastly, it is just critical that these partnerships engage over the long term to achieve those much sought-after long-term (and sometimes intangible) impacts.

Acknowledgements
The researchers among the authors owe a great debt to the pastoral families who have welcomed us into their lives and homes around the world. We also thank past co-authors who have contributed to the thinking that resulted in this paper, including María Fernández-Giménez, Kathleen Galvin, Julia Klein, Cara Steger, Anne Nolin, Catherine Tucker, Julia Parrish, Hailey Wilmer, Lauren Porensky, Justin Dermer, David Nkedianye, Dickson Kaelo, Moses Neselle, Leonard Onetu, Mohammed Said, Joseph Ogutu, Elisa Oteros-Rozas, Federica Ravera, Umed Bulbulshoev, and Daler S. Kaziev.

References


Engaged Research Can Advance Knowledge AND Promote Positive Change Among the Rural Poor

Coppock, D. L.

1Professor Emeritus, Department of Environment & Society, Quinney College of Natural Resources, Utah State University, UMC 5215 Old Main Hill, Logan, UT USA 84322-5215; layne.coppock@usu.edu

Key words: farming systems research & extension; participatory rural appraisal; action research; innovation systems; research for development

Abstract

There is increasing interest in investigative processes known as “Engaged Research.” Such approaches include aspects of Farming Systems Research & Extension, Participatory Rural Appraisal, Participatory Action Research, and Innovation Systems. Engaged Research—a term recently popular in the USA—is founded on long-term relationships among stakeholders and emphasizes problem-solving based on co-production of knowledge. We are now at a time when science-based knowledge should be implemented to improve the lives of the rural poor under the triple threat of poverty, natural resource degradation, and climate change. Traditional ways of conducting applied, academic study can be reconfigured to this end, improving research effectiveness beyond publications. The objective of this paper is to review the author’s experiences concerning four Engaged-Research projects and summarize lessons learned. Projects include improving risk management among pastoralists in Ethiopia as well as enhancing climate-change adaptation among pastoralists and small-holder farmers in Ethiopia, Nepal, and Uganda. Project outcomes have included economic diversification of households, empowerment of women, and water-resource development in addition to research outputs. Key elements of this approach include: (1) Joint identification of major problems and solutions; (2) trust building among stakeholders; (3) peer-to-peer learning; (4) investments to build human and social capital; and (5) facilitating growth of stakeholder self-help networks. Given there are typically positive effects of Engaged Research on stakeholders, why aren’t such approaches more common? The answer lies in the narrow incentives governing academia and development organizations; such incentives reward traditional ways of working rather than reflecting development impacts in the field. Other obstacles include the transaction costs and need for sustained funding in support of engaged activity from beginning to the end of a project. Researchers in developing nations can become involved in Engaged Research. How such scientists can navigate traditional incentive structures and enhance fund-raising for Engaged Research are reviewed.

Introduction

Researchers and development practitioners who work with the rural poor hope their efforts will lead to positive, sustainable changes in people’s lives. Reality, however, indicates this is difficult to achieve. One reason is that academic study rarely translates into practical recommendations; another is that development actions tend to be donor-driven and not evidence-based. Keeping community members out of the loop when research or outreach is planned promotes project irrelevance and undermines stakeholder buy-in. But a traditionally minded researcher may counter with the belief that, “My role is only to generate and publish knowledge; whether it is ever used is someone else’s problem.” This is a perfectly logical position—researchers often feel they can only do so much given limited time and other resources, and must focus on their core mandate. Here it is contended, however, that researchers and other change agents can expand their horizons to better embrace integrated projects that unite science and stakeholder participation (Pound et al., 2003). This is because the life circumstances for the rural poor are increasingly dire, and development professionals of all stripes should aspire to help foster positive changes in the drylands (Briske et al., 2020). Applied research
thus needs to be used, not just reported and left on the shelf. Scientists and development practitioners often become entrenched in “safe,” conventional ways of working, and lack exposure to innovative ways to collaborate and generate a greater array of real-world impacts. Indeed, there are few incentives to act differently. The objective of this paper is to provide examples as to how improved connectivity among stakeholders in rural-development processes can advance knowledge and foster more progress on the ground, largely based on the experiences of the author. An array of similar, action-oriented approaches (Shaner et al., 1982, Whyte 1989, Chambers 1994, Röling 2009) are grouped here under the term Engaged Research (Whitmer et al., 2010), a concept now getting traction among American universities (Coppock 2019). Benefits and challenges of Engaged Research will also be reviewed.

**Materials and Methods**

The approaches used for projects summarized in this paper and referenced above include: (1) Farming Systems Research & Extension (FSRE), (2) Participatory Action Research (PAR), (3) Participatory Rural Appraisal (PRA), (4) Innovation Systems (IS), and Engaged Research (ER). Key elements are summarized in Table 1.

Table 1: Key elements of various collaborative or action-oriented research approaches as practiced in pastoral or farming areas world-wide. Approaches are listed from top to bottom in a rough chronological order of their appearance in academic or rural development discourse.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Reference</th>
<th>Key Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farming Systems Research &amp;</td>
<td>Shaner et al.,</td>
<td>Integrated collaboration between research and extension components; tends to emphasize technical issues in understanding complex production systems</td>
</tr>
<tr>
<td>Extension (FSRE)</td>
<td>(1982)</td>
<td></td>
</tr>
<tr>
<td>Participatory Action Research</td>
<td>Whyte (1989)</td>
<td>Iterative, step-wise problem solving with multi-sectoral applications (i.e., education, health, agriculture, etc.)</td>
</tr>
<tr>
<td>(PAR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participatory Rural Appraisal</td>
<td>Chambers (1994)</td>
<td>Prioritized community-based problem diagnosis with identification of locally sustainable solutions; also with multi-sectoral applications as above</td>
</tr>
<tr>
<td>(PRA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovation Systems (IS)</td>
<td>Röling (2009)</td>
<td>Similar elements with FSRE and ER, but more emphasis on community-driven innovation and creation of integrated stakeholder networks to best achieve project goals. Networks can include governmental, non-governmental, or community-based organizations (GOs, NGOs, CBOs); also academics, etc.</td>
</tr>
<tr>
<td>Engaged Research (ER)</td>
<td>Whitmer et al.,</td>
<td>Encompasses multi-stakeholder interactions and outputs for research-based problem-solving over long time-frames on a project; embraces a novel mind-set for traditional, applied researchers in the USA</td>
</tr>
<tr>
<td></td>
<td>(2010)</td>
<td></td>
</tr>
</tbody>
</table>

While the approaches listed in Table 1 have distinct scholarly roots, they can yield similar project outcomes depending on how they are used. There is rarely a strict “cook book” approach for either practitioners or applied researchers when using these approaches. And approaches can be combined in an adaptive fashion. The ideal situation where all could be combined is illustrated in Table 2. In the author’s experience, his involvement in several consecutive projects in the Borana Plateau of southern Ethiopia from 1985 to 2018 offers a serendipitous case-in-point from a post-hoc retrospective, with the centerpiece being the USAID-funded Pastoral Risk Management (PARIMA) project.
Table 2: Temporal sequence of approaches used on the Borana Plateau of Southern Ethiopia, 1985 to 2018.

<table>
<thead>
<tr>
<th>Years</th>
<th>Approaches</th>
<th>Funding Source</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985-1994</td>
<td>System Analysis</td>
<td>International Livestock Center for Africa (ILCA)</td>
<td>Compilation of numerous discrete studies into a synthesis volume (Coppock 1994) revealed the need to diversify the pastoral economy and better manage risks of drought given population pressure. In one sense this substituted for an FSRE perspective.</td>
</tr>
<tr>
<td>1991-2015</td>
<td>Quest to Problem Solve</td>
<td>Not Applicable</td>
<td>In retrospect, Coppock (1994) gave the impetus to focus on pastoral economic diversification and risk management as problem model solutions. This embodied an ER worldview.</td>
</tr>
<tr>
<td>1994-1997</td>
<td>Applied Study of Household (HH) Risk Management</td>
<td>Utah State Univ.; Rockefeller Foundation</td>
<td>Study of details of HH asset diversification in pastoral (livestock) and non-pastoral (banking) spheres to better manage risk. Embraced conventional, socioeconomic research methods.</td>
</tr>
<tr>
<td>1997-2009</td>
<td>PRA; PAR; IS</td>
<td>USAID Global Livestock CRSP; USAID Country Missions; Utah State Univ.</td>
<td>PARIMA project; PRA used to confirm and enrich problem diagnosis; identified diversification as key, women as change agents; PAR used to strengthen pastoral capacity-building efforts; IS used to expand problem-solving via stakeholder networks of GOs, NGOs, CBOs, academics, etc. (Coppock 2019)</td>
</tr>
<tr>
<td>2013-2018</td>
<td>Applied Study of HH Asset Diversification and Rural/Urban Linkages</td>
<td>USAID Adapting Livestock Systems to Climate Change CRSP</td>
<td>Study of details of HH asset diversification in pastoral (livestock/rural) and non-pastoral (urban/banking) spheres to better manage risk. Embraced conventional, socioeconomic research methods (Coppock et al., 2018). Still embodied an ER worldview. Overall effort ceased by Coppock et al., when funding networks ended. Could continue with more PRA, PAR, IS to enhance pastoral development prospects.</td>
</tr>
</tbody>
</table>

Results

While an ER perspective has been embraced for various projects over the past 20 years—and subsequent projects benefitted from lessons learned in previous projects and hence became more efficient—each project has differed in terms of funding support, duration, research outputs, and development impacts (Table 3). Importantly, all four projects identified and implemented solutions to local problems within a short period of time, thanks to reliance on PRA and PAR. Variation in project funding has been the single most important factor in overall project impact and success; high funding levels for PARIMA allowed for major investments in research, human capacity-building, outreach, and creating a large IS stakeholder network (Coppock 2019). Project impacts from PARIMA are still ongoing today. In contrast, in other situations the lack of an ability to expand project support beyond 2-3 years markedly limited project impacts, despite that many interventions have been locally sustained post-project. Funding is also needed to incentivize IS networks (Table 2); when funding had dried up for PARIMA by 2009 the IS network quickly faded. Fortunately, however, continued growth of PARIMA no longer depended on the network; the IS was only essential early on.

Table 3: Features of four Engaged Research projects undertaken in chronological order by the author and colleagues, 1997 to 2018. Projects varied greatly with respect to funding levels; PARIMA was a USD multi-million effort while KALO was at a USD half-million level; Nepal (USD 25,000) and Uganda (USD 3,000) were funded at much lower levels.
Research outcomes contrasting engaged and conventional research approaches are shown in Table 4. Based on the author’s experiences, research innovation is higher under engaged formats because insights from co-produced knowledge are superior; research hypotheses are improved beyond what is offered in the scientific literature and action-oriented study provides better hypothesis testing. Problem-solving also benefits from testing ideas (theory) in real-world settings. The down side of engaged approaches includes the need for more funding that is also flexible. Transaction costs incurred when interacting with project stakeholders is another challenge that is often avoided when just conducting conventional research. Increased time involved in transaction costs may detract from the time devoted to data analysis and publication. Research risk occurs when the priority study topics that emerge from communities fail to coincide with the main scholarly interests of scientists.

Table 4: Differences between participatory and conventional research approaches. Source: Adapted from Coppock (2019).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Engaged Research</th>
<th>Conventional Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Innovation</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Publication Output</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Problem-Solving</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Funding Required</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Transaction Costs</td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>
Discussion

Many researchers may review these findings and conclude that while ER is indeed a noble and personally rewarding undertaking, the challenges of altering how one works in academia or government are too great. In particular, securing funding and new partnerships to conduct ER appear daunting. Such arguments are valid and scientists may rather aspire to broaden their impacts in the real world by doing a better job of communicating research results to development stakeholders. Such efforts could help fill “knowledge- or technology-transfer gaps” often found in developing nations due to outreach underinvestment (Coppock 2019). These gaps are dealt with by Extension faculty at land-grant schools in the USA, but a dominance of top-down thinking is a problem. This process could benefit from more co-production of knowledge via ER.

Applied researchers in developing nations may be well placed to adopt ER, however. In the experiences of the author, such scientists are often motivated by the idea that research should have practical utility and serve citizens in need. One obstacle to adopting more ER is traditional administrations that dole out rewards based on conventional research (Witmer et al., 2010). This is changing, however; researchers can conduct conventional and ER work, and public accolades for generating real-world impact from ER can be viewed very favourably by unit leaders at research institutions (Coppock 2019).

Another challenge becomes logistics and funding for ER. Applied researchers in developing nations actually have an advantage in conducting ER because target communities can be local and hence accessible over long periods of time. Securing funding is another problem in general. Because ER offers prospects of development impact, this may be advantageous in generating research monies. Researchers can seek partnerships with communities and change agents to create fundable ER projects. Efforts to generate crowdfunding can also occur (Shafi et al., 2019). As researchers gain expertise with development via ER this opens doors to consulting. In conclusion, benefits of ER are diverse and justify more adoption of the approach.

Acknowledgements

The author thanks K. Galvin for spearheading this symposium. Support for the author to present this paper online at the Joint XXIV IGC and XI IRC was provided by the Dept. of Environment & Society at Utah State University.

References


Shafi, K., Sauerman, H., and Franzoni, C. 2019. This is how crowdfunding can level the research playing field. The World Economic Forum and VoxEU. https://www.weforum.org/agenda/2019/02/crowdfunding-money-for-research-levels-the-playing-field/


By Akall, G.L.
United Nations Environment Programme (UNEP)

Key words: climate change adaptation; irrigation development; discourses; Turkana

Abstract
Irregularization has long been promoted in Africa’s drylands as a means to improve food security and livelihoods. Turkana County, one of the driest regions of Kenya, has a long history of irrigation interventions, extending from the colonial era to the present. The recent discovery of two huge water aquifers in the arid Turkana region, Kenya’s Vision 2030 and devolution has fed into enthusiasm for irrigation as an excellent solution to the multiple problems in the region against other activities like pastoralism. This is in spite of a history of failed irrigation developments in Turkana (Hogg 1987). This paper explores the power relations, knowledge and discourses of irrigation development in Turkana County, northwest Kenya in the 20th and 21st Century. It will compare irrigation development in the 20th century with a more recent set of programmes that have emerged since the turn of the 21st century. This paper focuses on Turkwel Irrigation Scheme Association (TISA), based along the Turkwel River in Loima sub-County in Turkana, which was established in 1966 but fell into disuse in the 1990s, but was re-started as part of an attempt to build a new resilience to climate change in the region. Methodologically, this article compares the views of developers with those of the Turkana people to examine the dominant irrigation development discourses across the two periods. Oral histories, participant observation, semi-structured interviews and focus groups discussions were used to collect primary research data.

Introduction
In Kenya, the drylands cover 80 per cent and host 14 million people, who depend on livestock keeping (Elmi and Birch 2013). Turkana County in northwest Kenya is 80 per cent arid. Turkana borders Ethiopia to the north, South Sudan to the northwest and Uganda to the west. Livestock herding is the main economic activity supporting about 62 per cent of the local populace, with 20 per cent depending on agro-pastoralism, 12 per cent on fishing and eight per cent on casual labour (Turkana County Government 2013).

Pastoralism as a way of life was and continues to be seen as outdated, backward and ill-fitting in a contemporary nation-state. Many governments present their drylands as fast tracts of empty, marginal, uncultivated or inefficiently used land (Lind et al., 2020; Turner 2011). Indigenous and local knowledge has enabled dryland residents to cope with climate variability historically. This indigenous knowledge can contribute to climate adaptation and mitigation (Dupar 2019). Turkana pastoralists have long used risk-spreading strategies, including moving livestock to the best pasture and water, keeping species-specific herds to take advantage of the heterogeneous nature of their imbalance environment, and keeping herds containing a mixture of species as insurance against total loss during drought (Flintan et al., 2013). However, Turkana has suffered a series of 30 severe droughts between 1963 and 2019. These droughts devastated livestock herds resulting in migration of destitute herders in search of new livelihood and relief (Lind et al., 2020). The impact of the droughts prompted planners to promote an agenda for shifting from pastoralism to irrigated agriculture and fishing (Lind et al., 2020; Adams and Anderson 1988; Hogg 1987). Irrigated farming was believed to provide a livelihood, and settlement would allow government services to be provided, such as clean water, health facilities, and classroom education (Little and Leslie 1999; Adams 1992). The planners saw the adoption of irrigation as a “privileged” technological response, while ignoring local experience (Adams and Anderson 1988). Yet irrigation was not new in East Africa. In Kenya, Adams and Anderson (1988) mention that the simplest indigenous irrigation
practice was recorded among the Turkana, who cultivated sorghum in the floodplains of the Kerio and Turkwel Rivers. Oba (1992) observes that ‘there are few instances where development plans have relied on historical analysis to deal with development issues at a regional level.’ In Turkana, between 1966 and 1978, small-scale irrigation projects were started as a means to reduce dependency on food handouts, (Anderson and Broch-Due 1999) sedentarisation, fishing, restocking and land restoration. The schemes were designed to provide a “new livelihood” (sedentary life) for nomads affected by drought or raiding (Little and Leslie 1999; Anderson and Broch-Due 1999; Adams 1992; Hogg 1987). Irrigation was thought to have great potential in helping the locals to adapt to drought, build resilience and improve food security. The intended role of pastoralists was to be operators (Catley et al., 2013). However, most schemes were capital intensive, technically complex and dependent on external commitments and expertise (Lind et al., 2020). The period between 1990 and 2011 was characterised by humanitarian interventions due to the intense droughts experienced in Turkana. From the early 2000s up to 2014, the frequency of recurrent droughts increased (Bersaglio et al., 2015). The 2011 Horn-of-Africa-drought stimulated a fresh interest in finding a solution to the drought problem. The renovation of irrigation schemes that had fallen into disuse then followed. In 2013, UNESCO discovered two huge water aquifers in the Lotikipi plains and Napuu near Lodwar, estimated to hold enough water to supply the entire Kenya for the next 70 years (Avery 2014b). This discovery triggered enthusiasm among developers. For more than six decades, development planners have continued to promote irrigation as a solution to the problem of drought in Turkana. In this paper, I explore the politics of irrigation development in the Turkwel Irrigation Scheme Association (TISA) to contrast the perceptions of local Turkana with those of developers.

Materials and Methods
Data used in this article comprises detailed oral histories, focus group discussions (FGDs), participant observation, and key informant interviews. The data was obtained from 60 agro-pastoralists, and town-dwelling households with the aim to build an understanding of the history and perceptions of irrigation development. I did fieldwork between February and September 2014. Then, follow up visit in May-August 2019. The follow up visit helped to observe progress of

irrigation interventions in Turkwel since 2014. During participant observation in 2014, I lived in Turkwel for eight months to observe daily activities of households working in the irrigation scheme. Oral history was used to record major events, such as drought, famine, diseases, raids and locust invasions. About 60 farmers were interviewed, who were mainly farmers. Five focus group discussions were conducted, each comprising six women and six men. They were conducted in the irrigated area, riverine forests, and villages. The FGD participants were purposively selected depending on their availability and willingness to participate in the study. FGDs were used to validate the information from all the interviews. I carried out research into irrigation development and I subsequently conducted in-depth research on the Turkwel Irrigation Scheme Association (TISA). This study area is located in Turkwel division of Loima sub-County, in the lower Turkwel River basin, Turkana County, northwest Kenya. The Government of Kenya and the Food and Agriculture Organisation of the United Nations (FAO) established the scheme in 1966 to support 175 destitute households as a famine prevention measure (Akall 2020). Loima, which is the focus of this study, has a population of 107, 795 people (KNBS 2019). The region of Loima has a significant nomadic pastoralist population with a few agro-pastoralists, mainly Ngmonia Turkana (one of the 19 Turkana sub-groups) who combined a focus on agriculture and livestock. Turkwel has an estimated population of 9, 315 (KNBS 2019). TISA is among the oldest of its kind in Turkana County. I purposefully selected TISA because of its long history of irrigation development processes.

Results
The findings reported in this article discuss the perceptions of local Turkana with those of developers, with particular attention to the Turkwel Irrigation Scheme Association (TISA), one of the earliest interventions to promote irrigation development. I provide personal accounts of respondents on TISA, which was established in 1966. The findings describe the history of flood cultivation and the introduction of ‘formal irrigation’ cultivation along the Turkwel River.

Flood cultivation among Turkana
Turkana pastoral economy involvement with the cultivation of small riverside plots can be traced first when they migrated into the region between 300 and 400 years ago (McCabe 2004).
Turkana began their southern migration after AD 1500. Evidence from oral histories with respondents shows *Ngmonia* Turkana exploited flood cultivation in the Kachaimeri floodplains continually for well over a hundred years where locals planted sorghum. More than 40 years after the introduction of sorghum in the area (Kachaimeri), but before any serious involvement of colonial officials in irrigation, the *Ngmonia* were joined by impoverished settlers from other Turkana sub-groups who moved in voluntarily to the Turkwel riverine forest to live by gathering wild food and hunting. By 1936, *Ekaru a Eesomalit* (the year Somali traders’ arrived in Turkana) some of the earliest Turkana settlers in this area had acquired gardens and also started cultivating sorghum gardens at Kachaimeri. The households increased from four to 14 before 1966, when modern irrigated agriculture and Turkana settlements were introduced in the area (see Akall 2020).

**Fragmentation of land and shrinking cropland**

The views of local people on irrigation investment are excluded in decision-making processes. For example, National Irrigation Board (now National Irrigation Authority) surveyors who designed the new main canal ignored local experience and ended up designing canal topography incorrectly. The schemes have taken over the dry season grazing areas, displaced pastoralists and blocked livestock from accessing the riverine forest and water sources because of fencing. Similarly, the problem of the thorny invasive *Prosopis juliflora*, locally known as *etirae*, which has altered the indigenous riverine forest of the area important for local livelihoods, remains invisible to planners. For instance, 430 hectares of irrigable land has been colonized by the invasive shrub *Prosopis juliflora* (*etirae* in Ng’atarkana), which is reducing the per capita land under irrigation and thereby placing a spatial limitation on livelihoods, especially shrinking cropland.

**Narratives of formal schemes and ‘official’ acreage**

Following the 2002 Water Act, which liberalized the water sector, particularly the management of the river basins, the creation of Water Users Associations (WUAs) occurred. Schemes like Turkwel Irrigation Scheme Association (TISA) were registered as a WUA in response to the reforms. This was to enable the scheme to access external support as a communal group. In 2014, there were six formal irrigation schemes in Turkwel location, which are registered as community-led water users’ associations (WUAs). The government, through NIB, surveys registered WUAs or formal schemes to get “official” acreage of the total irrigated area and ‘potential’ irrigable land. As a counter-mapping, this study challenged the visible “official” irrigation measurement. For example, the potential irrigable area and altered by *Prosopis* in TISA as mapped by local farmers in June 2014 was 212 hectares, as opposed to the NIB’s 175 hectares. The farmers estimate the irrigable area more highly than the organisations because of their local understanding of the history of irrigation activities and practices in the area. For instance, TISA initially had 11 blocks but five blocks have been swallowed by *Prosopis juliflora* (Interview with TISA official).

**Missing local knowledge in ‘formal irrigation’ development**

Local voices are excluded and silenced in policy processes. One elderly farmer commented: “We demand involvement in every aspect of development. We should not be excluded because of our illiteracy. Generations depend on this scheme for survival” (Interview with a 82-year-old farmer and TISA labourer, June 2014). Another farmer, a retired field extension officer at the TISA scheme, explained: “While NIB are rehabilitating the canal, they do not want us to get near where they are working” (Interview with a farmer, March 2014). The locals and NIB also knew that the contractor lacked the technical capacity to carry out the work. A farmer said: “The contractor excavated the canal without considering the topography of the area. They missed the older canal survey and excavated a new one, which was poorly levelled. We told them to follow the old survey, but they would hear none of it” (Interview TUR64). Respondents said that NIB ignored past experience of farmers. The agricultural engineer told me: “We advised NIB to involve farmers, who understood how the older canal was designed and worked. Thereafter, NIB involved a few farmers” (Interview in July 2014).

**Discussion**

This article suggests that local Turkana exploited flood cultivation well over hundred years before the introduction of ‘formal irrigation’ development in the lower Turkwel River basin. This evidence challenges the narrative of irrigation as ‘privilege technological’ solution to the problem of drought in Turkana. It shows how Turkana combined livestock herding and sorghum cultivation, which was complimentary to each other unlike developers’ notion of making destitute herders...
to full-time crop farmers through settlement and formal irrigation. As argued by Dupar (2019), indigenous knowledge coupled with scientific innovation can contribute to climate adaptation and mitigation. The narratives of ‘potential’ irrigable land and formal schemes characterize irrigation development resulting in exclusion of local cultivators with knowledge and history of flood cultivation. There is need for developers to promote the adoption of indigenous knowledge and practices to help local cultivators to adapt to the risks associated with climate change.

Acknowledgements
The University of Cambridge, The Smuts Memorial Fund and the British Institute in Eastern Africa funded my fieldwork in Turkana, Kenya. Thanks to my supervisor Liz Watson who provided guidance during my PhD research and Kathy Galvin, family and friends for continued support. Many thanks are due to the residents of Turkwel for their time, patience, and hospitality.

References
Avery, S. 2014b.Turkana County’s aquifers and irrigated crop development prospects—some reasons to be cautious. Improved data. Discussion brief, DLCI.
Dupar, M.2019. IPCC’s Special Report on Climate Change and Land: What’s in it for Africa? Cape Town: Climate and Development Knowledge Network, Overseas Development Institute and SouthSouthNorth.


Africa makes a relatively minor contribution to global greenhouse gas emissions compared with developed nations. Yet, the African continent will be increasingly vulnerable to climate change processes in the coming decades. Critical challenges include meeting basic needs for food, water, shelter, and other necessities without undermining biodiversity and ecosystem services. Coordination efforts to address multiple global change-related stressors has generally occurred at the national level and taken an external approach, with national governments favouring collaboration with foreign-based NGOs and other international institutions. However, the involvement of actors at the local level correlates with decisions that are better adapted to local social-cultural and environmental contexts, reducing implementation costs, and increasing trust, thereby increasing the equity and efficacy of decentralized approaches. This paper examines indigenous and local knowledge of climate change and its impacts. It addresses climate and environmental change from the perspectives of Kenyan pastoralists who identified a myriad of environmental issues that occur and interact at different scales. They also identified ways forward at several scales, from the local to the global. The continued functioning of ecosystems for local populations will depend critically upon sound policy, planning, and practice that includes pastoralist leadership.

Introduction

Global drylands comprise over 40 per cent of the earth’s land surface, support millions of pastoralists, and account for half of the world’s livestock. However, climate change and socio-economic drivers rapidly alter dryland social-ecological systems (SES). While climate variability defines drylands through seasonality and significant interannual fluxes in rainfall, the variability is expected to increase (Prăvălie et al., 2019). As a result, there are expected increases in total dryland areas, especially in arid grasslands (Jung et al., 2020). Yet, East Africa climate models suggest the future holds an increase in short-season rains with more flood and locust events (Cook et al., 2020).

Recurring droughts change ecological structure and function over time (Stringer et al., 2017). For example, the economics of livestock production changes as plant species important to cattle disappear, and invasive plants species unpalatable to livestock make it harder for herders to find pastures suitable to their herds. In addition, as cattle numbers decrease, household livestock species composition often changes to increasing numbers of sheep, goats, and sometimes camels. Human population pressures make earning a living solely from livestock untenable in places. The livestock to human ratio has been declining due to the loss of livestock during drought and population growth forcing change in land use. Climate and outside forces conspire to replace livestock herding with large-scale agriculture, mining, oil and gas extractive industries, solar and wind energy, urbanization, and infrastructure expansion (Galvin et al. 2020). Communal land tenure with customary use rights and management of land in the hands of communities is increasingly being privatized by non-pastoralists and pastoralists alike (Reid et al. 2014).

Pastoralists understand the drivers of change, the impacts of the changes, and potential solutions. This study sought to understand the implications of climate and socio-economic changes to address solutions for a resilient future in Kenyan drylands from the perspective of pastoralists. A series of focus groups, community workshops, and interviews were conducted over two periods in 2011.
Methods and Study Site

A series of focus groups, community workshops, and interviews were conducted in the Pastoral Transformations for Resilient Futures research program. Seventy-nine people were part of gendered focus groups and in two workshops. Workshop participants came from Turkana, Garissa, Narok and Kajiado counties, Kenya. Participants examined how changes in climate, ecosystems, livelihoods, land tenure and broader Kenyan society are interacting to shape pastoralist well-being and how local peoples are working to adapt to these changes. Additionally, 25 pastoralists were interviewed on livestock holdings, water availability, state of pastures, livestock management, livelihood diversification, changes in weather patterns, pastures, livestock condition and solutions to climate change impacts. The goal was to develop a set of concrete actions to address the myriad changes occurring in their social-ecological systems.

Results

<table>
<thead>
<tr>
<th>Northwest (Turkana)</th>
<th>Northeast (Garissa)</th>
<th>Southeast (Kajiado)</th>
<th>Southwest (Narok)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floods in 2010 rains</td>
<td>T increase</td>
<td>Droughts have become long and frequent.</td>
<td>Irregular rain patterns, the long and short rains</td>
</tr>
<tr>
<td>Migration to neighboring countries</td>
<td>More frequent droughts &amp; floods</td>
<td>New diseases such as blue tongue</td>
<td>Violent, scattered storms</td>
</tr>
<tr>
<td>T increase up to about 37-40 degrees C</td>
<td>Disappearance of grasses</td>
<td>High evaporation - causes drying up of the soil</td>
<td></td>
</tr>
</tbody>
</table>

Project participants first described several changes occurring in their regions. Just two changes are described here (see Galvin et al., 2020 for more on this project). Table 1 shows how people perceived changes in weather in the four regions, and the data shows wide differences in weather and impacts depending on where people came from. A second change (not shown) was that people from each region agreed on a general trend throughout Kenya of drying water sources. These climate changes and the land tenure and land-use changes have resulted in land fragmentation (Galvin et al., 2008). These changes have culminated in numerous other changes that have been well documented throughout East Africa (e.g., Catley and Scoones 2013; Nkedianye et al., 2019). For example, livestock management was changing throughout Kenya, including disrupted livestock movement routes and a general move towards increasing numbers of small stock and a decrease in cattle numbers. Livelihoods were diversifying with women’s economic activities such as selling livestock, poultry, and handicrafts. All participants agreed that investing in children’s education was occurring and that people wanted to be near other social services such as clinics and markets. How was the future regarded? Climate change and the other changes were big challenges in 2011 and were expected to increase in the future. Scenarios of the future of pastoralism were identified. The pastoralists identified three different outcomes to climate change: improvement of pastoralism, the transformation of pastoralism, or abandonment of pastoralism (Figure 1). In the first scenario, actions included improving pro-pastoralist infrastructures such as water resources and mobility, diversification of livestock species, and access to markets. Actions under the transformation of pastoralism were livelihood diversification, expansion of women’s roles, education opportunities, and new land management methods. The last scenario of abandoning pastoralism was an undesired prospect, but workshop participants perceived...
it as a future that should be contemplated given the current climate and other pressures on their SES. The actions included urbanization, commercialization of livestock operations and privatization of all land. These actions would put an end to pastoralism and transform the social-ecological system into something new (Galvin et al., 2020).

Discussion
Climate never acts in isolation, but rather there are many interacting factors at various scales affecting drylands. The data suggest there is no single solution for adaptation to dryland changes. Yet, dryland policy has generally focused on ‘repairing’ drylands from degradation by indigenous production systems. Global policy-science assessments like the SDGs and the IPCC have goals and policies focused on national levels relying on countries’ abilities to implement policies to achieve the goals. Most of the policies are ‘one size fits all’. Research on comparative studies among pastoral regions and scenario planning can demonstrate the variability among regions but also that pastoralists are very aware of the consequences of various adaptation strategies.

Pastoralists are not helpless victims of climate change. Though brief, the data shows that pastoralists are very aware of changes occurring, have implemented adaptations, and have thought about scenarios of future changes. Pastoral engagement in climate change decision-making is essential in partnerships and collaborations for a just and equitable transformation to change.

Acknowledgements
Sincere thanks to all the participants who provided knowledge and expertise in the workshops, focus groups and interviews. Thank you to the team that made this project possible, including David Nkedianye and Dickson ole Kaelo, Mohammed Khalif and Gregory Akall, Robin Reid, Jesse Njoka, Joana Roque de Pinho and Philip Thornton. This project, the Pastoral Transformations for Resilient Futures research program, was funded by the USAID Climate Change Livestock Collaborative Research Support Program that changed its name to Feed the Future Innovation Lab for Collaborative Research on Adapting Livestock Systems to Climate Change.

Notes
1Videos produced as part of the study: Maasai Voices on Climate Change (and other changes too): https://vimeo.com/73980798; Pastoralist Voices on Climate Change: https://www.youtube.com/watch?v=765l9XmMpDY. Of God, Rain and Motorbikes: https://vimeo.com/65117460

References


THEME 3: LIVESTOCK PRODUCTION SYSTEMS

Topic: Climate Change; Adaptations and Resilience of Livestock Systems
Assessing the potential of diverse forage mixtures to reduce enteric CH$_4$ emissions

Loza, C.$^1$; Verma, S.$^1$; Wolfgram, S.$^2$; Susenbeth, A.$^2$; Blank R.$^2$; Taube, F.$^1$; Loges, R.$^1$; Hasler, M.$^3$ and Malisch, C.S.$^1$

$^1$ Grass and Forage Science / Organic Agriculture, Christian-Albrechts-Universität zu Kiel, DE-24118 Kiel
$^2$ Animal Nutrition and Physiology, Christian-Albrechts-Universität zu Kiel, DE-24118 Kiel

Key words: greenhouse gas emissions; bioactive herbs; SF$_6$ measurements; Hohenheim gas test; plant specialized metabolites

Abstract

Enteric methane (CH$_4$) is the main source of agriculture-related greenhouse gasses. Conversely, customers demand pasture due to both perceived and real benefits regarding animal welfare, environmental aspects, and product quality. However, if implemented poorly, CH$_4$ emissions can increase, thus contributing to climate change. One promising option to reduce enteric CH$_4$ emissions is plant specialised metabolites (PSM), particularly tannins. Consequently, we conducted two complementary experiments to determine to what extent enteric CH$_4$ emissions can be reduced and how this affects milk yields: a) an in vivo experiment with grazing Jersey cows, where CH$_4$ emissions were quantified using the SF6 tracer technique, and b) an in vitro experiment using the Hohenheim gas test. In the in vivo experiment, a binary mixture consisting of perennial ryegrass (Lolium perenne) and white clover (Trifolium repens) was compared against a diverse mixture consisting of eight species, including birdsfoot trefoil (Lotus corniculatus) and salad burnet (Sanguisorba minor). In the in vitro experiment, the eight species from the in vivo experiment were combined in binary mixtures with perennial ryegrass in increasing proportions to determine the mitigation potential of each species. Results show an increase in milk yield for the diverse mixture, although higher CH$_4$ emissions also accompany this. Nevertheless, these emissions are lower across both mixtures when compared with similar trials. This is probably due to a very high digestibility of the ingested forage. With the in vitro experiment, we confirmed a substantial potential for CH$_4$ reduction when including species-rich in PSM. However, those forbs with the higher anti-methanogenic potential were only present in minor proportions in the pasture. Hence, further research will be required on how to increase the share of the bioactive species with lower competitiveness and confirm their potential in vivo.

Introduction

Enteric methane is a by-product of fibrous feed’s ruminal fermentation, allowing the ruminal ecosystem to dispose of the metabolic hydrogen produced during microbial metabolism (McAllister and Newbold, 2008). This is problematic for two reasons: a) methane emissions represent an energy loss, contributing to inefficient digestion, and b) enteric methane represents 44% of anthropogenic methane emissions, thus contributing to climate change (Gerber et al., 2013). However, grazing ruminants have the evolutionary advantage of producing food (meat and milk) from grass despite this environmental impact. Otherwise, marginal lands may produce edible energy and protein for humans. Additionally, grazing systems are the most cost-effective ruminant production system and contribute to soil carbon sequestration (hence contributing to climate change mitigation), biodiversity, and animal welfare (Dillon et al., 2005). Therefore, grazing dairy systems appear beneficial for an environmentally friendly and economically viable production (Peyraud et al., 2010; Thomet et al., 2011). Additionally, the use of pastures has been shown to be positively linked to consumer preference (Kühl et al., 2017; Weinrich et al., 2014). With methane currently
being one of the biggest environmental burdens from dairy and beef production, mitigation strategies for reducing GHG emissions are needed to maintain the benefits of grazing-based ruminant production systems while alleviating the negative impact on the climate.

One promising option to reduce enteric methane emissions are condensed tannins (CT). In the rumen, CT bind with dietary protein, thus protecting it from enzymatic hydrolysis and reducing enteric methane production (Jayanegara et al., 2012). Furthermore, these complexes dissociate due to changes in pH in the abomasum or the small intestine (Wang et al., 1996), thereby releasing the protein for post-ruminal digestion. As a result, including species into the animal’s diet containing plant secondary metabolites (PSM), particularly CT, is hypothesised to reduce methane emissions and increase nutrient use efficiency. This solution is particularly promising as improving species richness can improve the swards, yields drought tolerance, and reduce nutrient input requirements (Jing et al., 2017). However, increasing plant diversity in swards strongly influences the nutritive value of the herbage. Consequently, the aim of this study was a) to determine to what extent enteric CH4 emissions can be reduced by increasing pasture diversity with CT-containing forage species, and how this affects milk yields (Experiment 1) and b) determine the required shares of each species in a mixture with ryegrass to reduce methane emissions significantly (Experiment 2).

Methods and Study Site

Experiment 1: In vivo study determining the potential of increased pasture diversity

This experiment was carried out between March and August of 2019 at Kiel University’s research farm “Lindholf” (Kiel, Germany. 53°40’N, 10°35’E). Twenty-four multiparous lactating Jersey cows were split into two groups based on the parity (3 ± 1), and were grazing either a binary mixture (Lolium perenne (Lp) and Trifolium pratense (Tp)) or a diverse mixture (Lp, Tr; Trifolium pratense (Tp), Lotus corniculatus (Lc), Sanguisorba minor (Sm), Cichorium intybus (Ci), Plantago lanceolata (Pl) and Carum carvi (Cc)). The experiment was conducted using a cross-over design and two main periods (P1 and P2) with two subperiods each. Five weeks before the first measurement period, all animals started grazing on the same paddocks, which were a selection of both the binary and diverse mixture to pre-adapt the rumen fauna to both pastures. Each sub-period consisted of 4 days of a pasture-specific adaptation period, followed by 4 days of measurements. Swards were strip-grazed at a daily herbage allowance of 18 and 14 kg/cow/day for P1 and P2, respectively. The target residue was 4 kg DM/cow/day. The cows were milked twice a day (0600 and 1600 h) throughout the study, and individual milk yield was recorded. Milk composition (protein, fat and lactose) was determined daily from morning and afternoon milk samples. Energy corrected milk (ECM) was estimated according to Sjaunja (1990), and enteric methane emissions were measured using the SF6 tracer technique reported by Johnson & Johnson (1995) as adopted by Gere & Gratton (2010) for a 4-day collection period. Herbage mass and botanical composition were estimated by cutting ten randomly chosen quadrats of 0.25 m² per plot to a height of 4 cm.

Experiment 2: In vitro study analysing defined mixtures of grass and legumes/herbs

In this experiment, ten species (those mentioned above eight from the diverse mixture, as well as Lotus pedunculatus (LoP) and Sanguisorba minor (Sm)) were combined in binary mixtures. Lolium perenne was used as a fixed partner, while the nine other species were added in six increments from 0 to 100%. For the in vitro analysis, samples of each species were collected separately from the diverse sward used in Experiment 1, before grazing, in early spring 2018, when the sward was in the late vegetative stage. Approximately 300 g of fresh plant material was cut to a residual height of 4 cm. Samples were immediately frozen and stored at -27 °C. Before analysis, samples were freeze-dried to a constant weight and milled to a particle size of 1 mm. The Hohenheim gas test (HGT) followed the procedure Menke and Steingass (1988) stated, determining total gas production and methane production of these forage mixtures. Forage quality parameters of all samples analysed in Experiment 1 and Experiment 2 were determined by near-infrared reflectance spectroscopy (NIRS) with a NIRSSystems 5000 monochromator (FOSS, Silver Spring, USA). Mathematical evaluation of the spectra was performed using the Modified Partial Least Squares method (WinISI software version 3, Infrasoft International, USA). The
percentage of digestible organic matter (DOM) was calculated using the enzymatic soluble organic matter (ELOS) and the enzymatic insoluble organic matter (EULOS). Calibration and validation were based on sample subsets of perennial ryegrass, legumes and forage herb species, which represented the whole spectral and chemical variability.

Results

Experiment 1

The chemical composition of both herbage mixtures on offer generally showed high quality, despite decrements over time. Mean values for OM digestibility of both mixtures were between 0.78 and 0.88, and the mean energy concentration-as NEL- was in the range of 6.7 to 7.7 MJ/kg DM throughout P1 and P2. On average, across periods, the binary mixture’s OM digestibility and energy content were 3.5% greater ($P<0.001$) compared to the diverse mixtures. In contrast, across both periods, crude protein (15.0 g/kg DM) and ADF contents (19.7 g/kg DM) of the binary mixtures were lower ($P<0.001$) when compared to the diverse mixtures (17.8 and 23.1 g/kg DM, for crude protein and ADF) across both periods. *Lolium perenne* was the predominant species in both mixtures. When comparing the botanical composition of the residual swards after grazing with that of the offered forage, a positive selection by grazing animals for the herb species in diverse mixtures could be identified, with herb shares have decreased by 60%, on average for P1 and P2, when compared to the offered herbage. The forage use efficiency (FUE) was similar between treatments over both periods yet with a non-significant tendency of a greater FUE in the diverse pasture (63 % vs 71% FUE on average, for binary and diverse mixtures, respectively, across P1 and P2). Averaged across both periods, milk yields (22.3 kg and 21.0 kg milk/cow/day for diverse and binary mixture, respectively) and ECM yields (26.9 and 25.7 kg ECM/cow/day for diverse and binary mixture, respectively) increased ($P<0.001$) when compared to the diverse pasture. However, daily methane emissions also increased in diverse pastures. Mean values were 18% greater ($P<0.01$) in diverse pastures, with mean values of 221 and 260 g CH4/day for binary and diverse mixtures, respectively. Mean values for methane emissions per kg ECM were 11% greater ($P<0.01$) in diverse, compared to binary mixtures, with 9.8 and 8.8 g CH4/kg ECM on average across P1 and P2, respectively. Over time, the methane intensity generally increased and was 11% lower ($P<0.05$) in P1 compared to P2, with mean values of 8.8 and 9.9 g CH4/kg ECM, respectively.

Experiment 2

*In vitro*, most species showed a linear tendency to reduce methane emissions with increasing legume/herb share, although this reduction varied significantly with the partner species. The greatest methane reduction was observed for *Sm* and LoP (-24 %, on average). The most common forage legumes, *Tr* and *Tp*, did not decrease methane emissions compared to *Lolium perenne*. Simultaneously, there was a linear reduction in total gas production (i.e. OM digestibility) in all species, and, similarly to methane production, the species with the greatest reduction were *Sm* and *LoP* (-28%, on average), followed by *Tr* and *Tp* (-21%, on average), *Lc* (-20%, on average), *Ci* and *Cc* showed the lesser reduction in total gas (-13%, on average). These differences in methane suppression potential were in agreement with the tannin composition, as the highest tannin concentrations were observed in *Sm* (47.6 mg/g DM) and *LoP* (20.2 mg /g DM). In contrast, all other species had only minor tannin concentrations less than 4 mg / g DM. However, while *Sm* contained entirely hydrolysable tannins (HT), *LoP* contained condensed tannins (CT). *Sm* also had the greatest energy contents with 7 MJ NEL / kg DM and *LoP* (20.2 mg /g DM). In contrast, all other species had only minor tannin concentrations less than 4 mg / g DM. However, while *Sm* contained entirely hydrolysable tannins (HT), *LoP* contained condensed tannins (CT). *Sm* also had the greatest energy contents with 7 MJ NEL / kg DM and an OM digestibility of 89%. These were lower in *LoP* at 6.1 MJ NEL/ kg DM and an OM digestibility of 80%. *Lolium perenne* also exhibited a high forage quality, with 6.5 MJ NEL / kg DM and an OM digestibility of 85%.

Discussion

The *in vitro* experiment results showed substantial potential to reduce methane production when including species-rich in PSM. *Lotus pedunculatus* and *Sanguisorba minor* are particularly interested since they showed the greatest reduction potential. However, the simultaneous reduction in OM digestibility (i.e. reduction in total gas production) when increasing the shares of these species in the diet might be an issue. Nevertheless, the cows grazing the diverse mixture in the *in vivo* experiment had excellent milk yields, comparable to Jerseys fed TMR diets with 32% concentrate *ad libitum* (Olijhoek et al., 2018). The fact that the cows in the present
study had milk yields similar to those of Jersey cows fed TMR with a high proportion of concentrates, despite slightly lower body weights (with 442 and 469 kg, respectively) indicates that forage of excellent quality was available on the pastures in general, as well as the cows having a high genetic potential for milk production. The high forage quality and genetic potential of the Jersey cows, as illustrated in the milk yield, can also explain, at least partially, the very low CH4 emissions and particularly the methane intensities. Generally, the CH4 emissions in the present study of 221-260 g CH4/cow/day were similar to values reported previously for Jersey cows, ranging from 258 to 321 g CH4/day (Münger and Kreuzer, 2006; van Wyngaard et al., 2018). However, compared to cattle with similar body weight, these emissions are substantially lower than the ~ 400 g CH4/day reported by Jonker et al., 2019. Additionally, due to the very high milk yields, the emissions per unit of milk were low. The reasons for increased CH4 emissions from cows that grazed the diverse swards are likely to be a combination of two factors. Firstly, the greater DMI (as indicated by the greater FUE) of herbage from the diverse mixture sward, and secondly, the lower OM digestibility of the diverse sward, which is to be expected due to the share of herbs rich in structural carbohydrates, such as ribwort plantain, and the temporal asynchrony between species and the corresponding difficulty in utilising all species under optimal conditions, thus resulting in increased proportions of stem fractions in many species (Bruinenberg, 2002). However, these forbs with the higher anti-methanogenic potential were only present in minor proportions in the pasture, probably because of a lack of competitiveness in a system with high grazing pressure. This might explain that their shares did not reduce methane emissions compared to the binary mixture in the in vivo study, contrary to the in vitro findings. Hence, while the overall very low emissions and high milk yields have identified the suitability of the grazing system for milk production with low methane emissions, with regards to the PSM containing forage plants, further research is needed to determine whether different mixture strategies or lower grazing intensities can improve their potential for grazing systems with dairy cows.

Acknowledgements
This research was made possible by funding from SusAn, an ERA-Net co-funded under European Union’s Horizon 2020 research and innovation program (www.era-susan.eu ), Grant Agreement n°696231, and the Federal Ministry of Food and Agriculture, Germany, Grant Agreement n°2817ERA13D.

References


Livestock corridors working as pollinator refuges and dispersal hotspots: lessons from Spain

Manzano, P. 1, 2, 3; García-Fernández, A. 4; Seoane, J. 1; Azcárate, F.M. 1; Iriondo, J.M. 4 and Peco, B. 1

1Terrestrial Ecology Group - Departamento de Ecología, Centro de Investigación en Biodiversidad y Cambio Global (CIBC), Universidad Autónoma de Madrid, Madrid, Spain;
2Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland;
3Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland;
4Área de Biodiversidad y Conservación, Universidad Rey Juan Carlos, Móstoles, Madrid, Spain

Key words: herbivore corridors; seed dispersal; pollination; landscape genetics

Abstract

Habitat fragmentation is one of the greatest threats to biodiversity conservation and ecosystem productivity mediated by direct human impact. Its consequences include genetic depauperation, comprising phenomena such as inbreeding depression or reduction in genetic diversity. While the capacity of wild and domestic herbivores to sustain long-distance seed dispersal has been proven, the impact of herbivore corridors in plant population genetics has not been observed previously.

We conducted this study in the Conquense Drove Road in Spain, where sustained use by livestock over centuries has involved transhumant herds passing twice a year en route to winter and summer pastures. We compared genetic diversity and inbreeding coefficients of *Plantago lagopus* populations along the drove road with populations in the surrounding agricultural matrix at varying distances from human settlements.

We observed significant differences in coefficients of inbreeding between the drove road and the agricultural matrix and significant trends indicative of higher genetic diversity around human settlements. Although they were only marginally significant, trends for higher genetic diversity along drove roads may be present due to the available sample size.

Our results illustrate a functional landscape with human settlements as dispersal hotspots, while the findings along the drove road confirm its role as a pollinator reservoir observed in other studies. Drove roads also seem to function as linear structures that facilitate long-distance dispersal across the agricultural matrix, while local *P. lagopus* populations depend on short-distance seed dispersal. These results highlight the role of herbivore corridors in conserving the migration capacity of plants and contribute towards understanding the role of seed dispersal and the spread of invasive species related to human activities. The coupling of traditional pastoralist practices with the phenology of plants and pollinators raises concerns about the environmental effects of current global land-use change.

This paper is based on García-Fernández et al., (2019).
Introduction

Increased habitat fragmentation is a major worldwide threat for ecosystems and biodiversity (Fahrig 2003), leading to genetic drift and reduction in within-population genetic diversity. Inbreeding depression impacts biodiversity conservation (Ouborg et al., 2006) or ecosystem productivity (Crutsinger et al., 2006). Measures to connectivity between isolated vegetation patches include boosting dispersal, a key element for reducing extinction risk, and is subjected to strong selective pressures (Cheptou et al., 2017). As a result, large wild herbivores functionally disappear from ecosystems (Bar-On et al., 2018). Livestock seed dispersal is a cheap and effective management tool with complementary dispersal modes that lead to an almost complete representation of the grassland community. Corridors for mobile livestock can increase the multifunctionality of the landscape by increasing landscape heterogeneity at a large scale, translating into higher biodiversity and the maintenance of pollination services (Odhiambo and Manzano, 2021). But does the proven capacity of livestock in achieving long-distance dispersal translate into an effective and determinant vector for gene flow across the landscape? Considering the similar corridors used by ancient wild migratory herbivores and livestock mobility routes maintained during centuries (Manzano Baena & Casas 2010), this question is very relevant to understand whether widespread mobile pastoralism can substitute the ecological functions of wildlife.

The livestock mobility corridors area also harbours a significant pollinator community in fragmented agricultural landscapes they cross, which is relevant in the current pollinator crisis in high-income countries (Hevia et al., 2016). The effect of either keeping them in use or leaving them just as a landscape element is also key to understanding the relevance of mobile pastoralism for ecological functionality.

Materials and Methods

Study Site

This study was conducted in the Conquense Drove Road (CDR), one of the major Spanish road droves (ca. 410 km long) that are still used for transhumant sheep and cattle herds that move every year from the cooler and wetter mountains of Teruel, Cuenca and Guadalajara provinces to the wintering dehesas in Sierra Morena at lower altitude (Oteros-Rozas et al., 2012). The area is between Quintanar de la Orden, Tomelloso and Villarrobledo municipalities, on a plateau (830-900 meters a.s.l.) of sandstones, loams and clay materials under continental Mediterranean climate, with a mean annual rainfall of about 500mm and severe summer droughts. The vegetation is a mosaic of agricultural dry cereal and sunflower croplands, abandoned fields and dry grasslands used by local flocks. Herds still cross the study area twice a year, timing their transit at two productivity peaks in May and October (Manzano-Baena and Casas 2010). However, their numbers are significantly lower than they have historically been, shrinking from about half a million heads in the 16th and 17th centuries to ca. 9000 heads of sheep and 1,200 heads of cattle nowadays (Bacaicoa Salaverri et al., 1993). Resident livestock, historically much more irrelevant, are currently relatively common in the landscape. They are kept at stables in urban settlements at night and graze grassland patches spread across the landscape. Drove roads to tend to avoid urban settlements and run tangentially. Hence, resident livestock does little use of them because of the somewhat radial pattern of land use, with urban settlements in the centre.

For this study, we selected Plantago lagopus L., an abundant annual or biennial forb that is self-compatible, with both wind and insects as major pollination agents (Sharma et al., 1993). It is estimated that a typical herd of 1,000 sheep would disperse ca. 2 million seeds per transhumance day in spring or 50,000 seeds in autumn. Such large dispersal, along with the faster dynamics in annual plants (overlapping generations in perennial plants may disturb some genetic descriptors due to the mixture of genotypes), makes them particularly suited to test genetic signals of dispersal in fragmented scenarios (Ewers & Didham 2006). Using specifically developed microsatellites, we compared genetic diversity and inbreeding coefficients of 6 P. lagopus populations along the drove road with 7 populations in the surrounding agricultural matrix, at varying distances from human settlements.

Results

Landscape factors governing genetic descriptors in P. lagopus populations

For two genetic factors analyzed (FIS or inbreeding coefficient, as a measure of inbreeding depression; and Ar, or rarefacted allelic richness, as a measure of genetic diversity), the geographic
variables showed a measurable effect. The distance to the nearest settlement had an impact on both inbreeding (FIS) and genetic diversity (Ar; Table 1), as had the interaction with population position (either in the livestock corridor or in the agricultural matrix) – although it was only marginally significant in the case of genetic diversity.

**Table 1:** Results of linear modeling of the inbreeding depression (FIS), and rarefacted allelic richness (Ar) on landscape factors. Source: [https://doi.org/10.7717/peerj.7311/table-4](https://doi.org/10.7717/peerj.7311/table-4)

<table>
<thead>
<tr>
<th>Genetic descriptors</th>
<th>Coefficient estimate (p)</th>
<th>model’s AICc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIS</td>
<td>$\chi^2 = 20.82, R^2 = 26%$, Gaussian spatial covariance structure.</td>
<td>0.001 -37.1</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.139 (0.028)</td>
<td></td>
</tr>
<tr>
<td>Distance to settlement</td>
<td>0.015 (0.032)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Position (drove road)</td>
<td>-0.015 (0.025)</td>
<td>0.280</td>
</tr>
<tr>
<td>Grassland cover</td>
<td>0.037 (0.009)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Distance x Position</td>
<td>-0.106 (0.037)</td>
<td>0.005</td>
</tr>
<tr>
<td>Ar</td>
<td>$\chi^2 = 10.51, R^2 = 72%$, Gaussian spatial covariance structure.</td>
<td>0.033 47.7</td>
</tr>
<tr>
<td>Intercept</td>
<td>8.056 (0.459)</td>
<td></td>
</tr>
<tr>
<td>Distance to settlement</td>
<td>-1.724 (0.548)</td>
<td>0.006</td>
</tr>
<tr>
<td>Position (drove road)</td>
<td>1.254 (0.666)</td>
<td>0.076</td>
</tr>
<tr>
<td>Distance x Position</td>
<td>1.282 (0.705)</td>
<td>0.070</td>
</tr>
</tbody>
</table>

Inbreeding (FIS) increased with distance from human settlements in the agricultural matrix but followed the opposite trend in drove road populations (Fig. 1a). The presence of nearby grasslands also proved to be a significant factor, showing higher rates of inbreeding at higher grassland cover (Table 1).

Genetic diversity (Ar) was negatively related with the distance to settlements, Ar values between matrix and drove road positions showed a pattern of convergence at short distances and divergence at high distances from human settlements, with the agricultural matrix then showing less diversity (Figure 1b) – although it was only marginally significant in the case of genetic diversity.

![Figure 1](https://doi.org/10.7717/peerj.7311/fig-4)
Interpretation of genetic results

Proximity to human settlements drives the hotspots for genetic diversity (Ar) in this landscape (Fig. 1b). The loss in genetic diversity with increasing distance to human settlements is weaker at drove roads (statistically marginally significant), mediated by the intense seed dispersal processes. Drove roads seem to function as linear structures facilitating long-distance dispersal across the agricultural matrix. In contrast, the local *P. lagopus* populations situated in the agricultural matrix depend instead on short-distance seed dispersal to recruit new individuals.

Drove roads could invert the inbreeding (FIS) that otherwise appears in distant populations from the agricultural matrix (Fig. 1a). The smaller selfing coefficient and the reduced influence over FIS observed along the drove road indicate their relevant role in providing pollination services. This relationship is even clearer after controlling for landscape effects, namely the presence of grassland patches in the vicinity of the studied plant populations that could harbour further pollinators. The negative relationship observed between such patches and the pollinators mirror Rico et al., (2014b). The explanation could rely on the flowering plants on such patches continuously grazed during the whole spring by resident sheep flocks.

Meanwhile, the transhumant herds graze on the drove road only at the end of the spring, following a “green wave” when the plants have already grained, relatively untouched during the flowering phase. While a greater coefficient of inbreeding is a genetic indicator that can be related to pollinator limitation (Turner et al., 1982, Van Etten et al., 2015), the structural role of drove roads as grassland corridors crossing agricultural landscapes has been proved to be determinant in supporting pollinator services (Hevia et al., 2016), which our study confirms. This result goes along with other studies that have observed provision of heterogeneity at the landscape level because of the drove road’s structural role, translated into higher biodiversity levels (Azcárate et al., 2013, Hevia et al., 2013).

Implications

The consistent effect of human settlements on genetic diversity and inbreeding results in a functional landscape of settled, high human density areas being hotspots of dispersal that modulate the genetic patterns of diversity, probably mediated by commercial livestock exchanges but also by other dispersal types, mainly human-mediated (Wichmann et al., 2009). However, the *P. lagopus* populations on the drove road don’t show to be affected by these types of dispersal, likely because their human use is much diluted and human activities are comparatively simplified and less dense, consisting just in accompanying or herding livestock. This confirms the role of human activities in the spread of invasive species. In contrast, moderate seed dispersal processes mediated by mobile livestock would modulate the necessary spread to avoid genetic depauperation.

The positive role of mobile pastoralism for pollinators, with movements that are coupled with the phenology of both plants and pollinators, highlights possible causes of pollinator decline in Europe. Even measures designed to comply with agri-environmental schemes are damaging to pollinators because of the lack of adaptation to such rhythms (Tanis et al., 2020). This could be a different outcome of the co-evolution of the European flora among now disappeared migratory megaherbivores (Vera 2000). A derived disruption of dispersal processes and the structural role for pollinators played by corridors themselves may further contribute to a generalized grassland biodiversity crisis motivated by land-use intensification (Gossner et al., 2016) and climate change – and on the latter, a potential decoupling of herbivore “green wave” movements from the phenology and seed availability also brings concerns (Berg et al., 2010). Mobile pastoralism can be a powerful, adaptive tool to prevent such crises.

Drove roads could invert the inbreeding (FIS) that otherwise appears in distant populations from the agricultural matrix (Figure 1a). The smaller selfing coefficient and the reduced influence over FIS observed along the drove road indicate their relevant role in providing pollination services. This relationship is even clearer after controlling for landscape effects, namely the presence of grassland patches in the vicinity of the studied plant populations that could harbour further pollinators. The negative relationship observed between such patches and the pollinators mirror Rico et al. (2014b). The explanation could rely on the flowering plants on such patches continuously grazed during the whole spring by resident sheep flocks.

Meanwhile, the transhumant herds graze on the drove road only at the end of the spring, following a “green wave” when the plants have already grained, relatively untouched during the
flowering phase. While a greater coefficient of inbreeding is a genetic indicator that can be related to pollinator limitation (Turner et al., 1982, Van Etten et al., 2015), the structural role of drove roads as grassland corridors crossing agricultural landscapes has been proved to be determinant in supporting pollinator services (Hevia et al., 2016), which our study confirms. This result goes along with other studies that have observed provision of heterogeneity at the landscape level because of the drove road’s structural role, translated into higher biodiversity levels (Azcárate et al., 2013, Hevia et al., 2013).

Acknowledgements
The making of this paper was funded through the Spanish MINECO, the Madrid Regional Government, the Instituto de Estudios “Don Juan Manuel” (Diputación de Albacete), the Helsinki Institute of Sustainability Science (HELSUS) and the International Union of Biological Sciences (IUBS).

References


Vera, F. 2000. *Grazing ecology and forest history*. CABI, Wallingford

The hunt for the “holy grail”: condensed tannins in perennial forage legumes


1 Grasslanz Technology Ltd; 2 AgResearch Ltd; 4 PGG Wrightson Seeds Ltd; 3 AgroParisTech,

Key words: Condensed tannin; forage legumes; methane; plant breeding; protein binding

Abstract

A recent advance using molecular biology has identified a transcription factor or master switch that can ‘turn on’ the condensed tannin pathway in white clover. As a result, the appropriate promoters allow biologically significant condensed tannin expression levels in leaf tissue. In vitro tests have demonstrated that the condensed tannins produced in white clover leaves can bind protein at a pH 6.5, as found in the rumen, and then release them at pH 2.5, the pH in the abomasum, before entering the small intestine for amino acid absorption. Additional tests have demonstrated that these condensed tannins can reduce methane production by up to 25% in the first 6 hours of incubation. The journey to this point and the challenges of delivering white clover cultivars with condensed tannin expression will be described.

Introduction

Forage legumes provide high protein feed for ruminants, either in single species swards such as lucerne or mixed-species swards containing grasses and clovers. These high legume diets improve animal production (Harris et al., 1997). However, there are downsides when protein is degraded in the rumen resulting in urinary nitrogen losses to the environment (Pacheco and Waghorn, 2008) and an increased susceptibility to bloat (Ledgard et al., 1990). It has long been understood that these negative effects can be mitigated by the protein being bound and protected from degradation in the rumen (Waghorn et al., 1987). Condensed tannins (CTs) are known to protect protein resulting in not only reduced nitrogen loss and reduced bloat but also reduced methane production (Pellikaan et al., 2011), reduced internal parasite burden (Villalba et al., 2010), and improved animal productivity (Waghorn 2008)). Unfortunately, the main legumes used in pastoral agriculture in temperate grazed grassland – lucerne, white clover and red clover do not produce sufficient condensed tannin levels in their leaves to be effective (Woodfield et al., 1998). However, a transcription factor or master switch that can ‘turn on’ the CT pathway present in white clover and lucerne has been identified using molecular biology approaches. The process of developing this new advancement for white clover and its impact on protein binding and methane production is described.

Methods

Plant materials The plant material used in this study are the progeny of genetically engineered white clover containing a transcription factor TaMYB14-1 from Trifolium arvense (Hancock et al., 2012, 2014); the production of white clover transgenic plants described in Roldan et al. (2019) and Woodfield et al., (2019). The backcross 2 (BC2) progeny, which was pairwise crossed to produce the seed for the field trial described below, were grown in a physical containment glasshouse in AgResearch Grasslands Campus in Palmerston North, NZ.

Field trial 2019 – USA

A total of 25 families derived from pair-crosses between 8 genotypes from a BC2 population (as shown in Table 1) where compared with 8 genotypes from white clover cultivar Mainstay, and 2 from Lotus corniculatus cultivar Goldie. Each of the 25 families were represented by
8 individuals. These were each characterised as being either homozygous (74 genotypes) or heterozygous (82) for the transcription factor, or not having the transcription factor (nulls) (44). Each plant was transplanted into a 30cm ring set into the ground.

Table 1: Crossing design for the production of the 25 families derived from pair-crosses between 8 genotypes from a backcross 2 population.

<table>
<thead>
<tr>
<th>BC2 Parent 1</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>B</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A randomised block design with 2 replicates (4 genotypes per family per replicate) was used with plants arranged in 3 double rows (to remove edge effects); the distance of plants within a double row was 30 cm; the distance of plants between double rows was 75 cm, and the distance between columns was 30 cm. Plants were grown in an insect-proof cage at a site in south Wisconsin managed by Great Lakes Agricultural Research Services (GLARS), Delavan, Wisconsin, USA under permit number 19-045-105rm issued by USDA Biotechnology Regulatory Service. Measurements were made of: shoot dry weight (at 5cm from the ground), CT levels (measured by extracting CTs from freeze-dried leaf material), leaf size, petiole length and stolon diameter.

Quantification of soluble and insoluble condensed tannins in white clover leaves

The total (soluble and insoluble) CTs were determined using freeze-dried leaf samples from the experimental site in GLARS, Wisconsin, USA. The CT extraction and assay methods are described in detail in Roldan et al. (2019) and Peel and Dixon (2007). First, soluble CTs were calculated spectrophotometrically at 640 nm against a standard curve of epigallocatechin (Indofine chemical company, Hillsborough, NJ) after reaction with 0.2% (w/v) 4-Dimethylamino cinnamaldehyde (DMACA) reagent in methanol-3N HCl. Next, insoluble CTs were calculated by determining absorbance values of the extract at 550 nm before and after boiling for one hour. Then, the absorbance values were converted to CT equivalent using a standard curve of purified CTs from white clover leaves. Finally, soluble and insoluble CTs were summed up to obtain the values for total CTs.

Protein binding assay

Purified CTs from the leaves of CTG-T1 progeny (# 1066) was used in the CT- protein binding assay using a protocol modified from Zeller et al. (2015) with bovine serum albumin (BSA) as the test protein. A protein binding experiment was conducted using 50 mM 2-(N-morpholino) ethanesulfonic acid MES buffer, pH 6.5. The same buffer but lower pH (pH 2.5) was used; the experiment was conducted in 3 replicates.

Methane production in vitro

To assess the effect of the condensed tannins in white clover leaves on total gas and methane production, leaf material was used in a small-scale incubation system following the procedure previously described (Muetzel et al., 2014). Three experiments were conducted with 4 substrate treatments (leaves from 2 high CT (HiCT) white clover plants; and wild-type white clover plants flowers and leaves), with 2 replications per treatment using rumen fluid from two different donors cows. There were two incubation bottles per replicate, one treated with polyethylene glycol (PEG) 6000 (control) and the other untreated. Each bottle contained 600 ± 15 mg of milled freeze-dried plant materials. Total gas and methane production were recorded after 6 hours of incubation. The percentage reduction was determined based on actual production with and without PEG.

Statistical analyses

Data were analysed using Minitab statistical software. Grouping information used the Fisher LSD method with 95% confidence limits to determine differences between means.

Results

Condensed tannin expression and plant growth

In the past two generations of progeny from the original transformants, we have shown evidence of a stable accumulation and enhancement of condensed tannins in white clover leaves (data not shown). This trend continues to this third-generation (T3) of progeny, plants which
are homozygous to the transcription factor TaMYB14-1 significantly produce elevated soluble and total CTs by up to 2.4-fold and 1.6-fold, respectively, relative to heterozygous individuals (see insert in Figure 1A). In comparison, individuals who did not inherit the TaMYB14-1 transgene produce significantly low (almost nil) CTs in the leaves (Figure 1A).

However, in terms of plant vigour, a yield penalty is being observed in individuals with higher CT levels (Figure 1B). There is an overall significant negative correlation (r = -0.619) between levels of CTs in leaves and plant growth. Nevertheless, when grouped by zygosity, plant growth was not significantly affected by the CT levels (Figure 1B). Previous observations show that the yield penalty is being reduced by selective breeding.

Condensed tannin effects on protein binding and methane production

Results of protein binding assay provided evidence that the purified condensed tannins from the leaves of HiCT white clover efficiently bound protein at a pH value that resembles the average ruminal pH. This was noted following incubation of the CT-protein mix in an aqueous MES buffer, pH 6.5. The CT-protein interaction formed complex molecules that precipitated into the pellet upon centrifugation, leaving an untraceable amount in the supernatant (Figure 2A). Upon resuspension of the pellet in an acidic buffer (pH 2.5), the CT-protein complex dissociated, and the protein was again detected in the supernatant.

Figure 1: Soluble condensed tannin (CT) in white clover leaves plotted against A) total CTs and B) plant vigour in null, heterozygous and homozygous individuals, as indicated. Each data point in A & B represents the mean of 2 measurements (8 & 12 WAP). In table insert in A, means within each column with different letters are significantly different by LSD (P value < 0.01)

Initial (over first 6 hours) depression of gas and methane production using an automated small-scale incubation system with rumen fluid added averaged about 12.5% and 25% respectively (Table 2) for two HiCT expressing leaf samples. Gas production is a measure of general fermentation (a positive attribute for animal productivity) and a 2-fold reduction in methane over total gases suggests that CTs have a greater impact on methane-producing microbes than the general microbial population.

Figure 2: Protein detected in the supernatant or pellet, as indicated, following incubation at pH 6.5 (A-B) and pH 2.5 (C) without (A) and with (B-C) white clover leaf CTs. The error bars indicate error mean square of 3 replicates.
Discussion
For over 70 years plant breeders have aspired to develop white clover capable of expressing biological significant levels of condensed tannins. Forage legumes such as white and red clover improve the nutritional quality of grazed pasture but also cause bloat as these feeds are fermented by rumen microbes. This rapid fermentation also contributes to environmental issues through higher methane emissions and high urinary nitrogen losses. Condensed tannins have been shown to reduce urinary nitrogen and methane production from grazing animals, reduce bloat, reduce internal parasite burden, and to improve animal productivity. This array of environmental, animal health and animal productivity benefits make condensed tannins the holy grail of forage legume breeding. Several forage legumes including birdsfoot trefoil and sainfoin do have good levels of condensed tannins but unfortunately these species fail to persist in intensively grazed pasture systems. Conventional approaches of phenotypic selection and breeding have failed to deliver condensed tannins in legumes that do persist under grazing such as white clover, red clover or lucerne. The transcription factor TaMYB14-1 has provided the opportunity to produce condensed tannins in white clover leaves at levels that will be effective in binding protein in the rumen, resulting in reduced methane production. The challenges to deliver this technology will include increasing yield while maintaining expression of condensed tannin levels, and gaining regulatory approval for its release from containment for general use in grazed pastures.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Additive</th>
<th>Total production (ml/g)</th>
<th>% Reduction Gas</th>
<th>% Reduction Methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT WC leaves</td>
<td>+ PEG</td>
<td>194.07</td>
<td>14.05</td>
<td>0.20c</td>
</tr>
<tr>
<td></td>
<td>- PEG</td>
<td>194.53</td>
<td>14.28</td>
<td></td>
</tr>
<tr>
<td>WT WC flowers</td>
<td>+ PEG</td>
<td>180.60</td>
<td>13.83</td>
<td>20.73a</td>
</tr>
<tr>
<td></td>
<td>- PEG</td>
<td>217.87</td>
<td>18.46</td>
<td>34.00a</td>
</tr>
<tr>
<td>HICT-1 leaves</td>
<td>+ PEG</td>
<td>159.62</td>
<td>10.84</td>
<td>16.40ab</td>
</tr>
<tr>
<td></td>
<td>- PEG</td>
<td>185.77</td>
<td>13.72</td>
<td></td>
</tr>
<tr>
<td>HICT-2 leaves</td>
<td>+ PEG</td>
<td>171.87</td>
<td>11.94</td>
<td>8.73b</td>
</tr>
<tr>
<td></td>
<td>- PEG</td>
<td>186.63</td>
<td>14.76</td>
<td>23.87a</td>
</tr>
</tbody>
</table>

Table 2: Effects of HiCT clover on total gas and methane production. Substrates were mixed with buffered rumen fluid collected from 6 different donor cows (representing 6 replicates) with and without PEG additive, then incubated in a fully automated small scale incubation system (Muetzel et al 2014). Total gas and methane production was recorded after 6 h incubation and % reduction (-PEG) was calculated relative to control (+ PEG). Means with different letters within each column under % reduction indicate significant difference at P<0.05.

Acknowledgements
Thanks to industry partners Grasslanz Technology Ltd, and PGG Wrightson Seeds Ltd, along with Ministry for Primary Industries (NZ) for funding this work. Thanks to Great Lakes Agricultural Research Services, Delavan, Wisconsin, USA for planting, maintaining and assisting with harvests of the field trial, and Rupinder Kaur for her assistance in CT extraction and assay

References


Understanding the effects of a tannin extract on forage protein digestion in the rumen and abomasum using a dynamic artificial digestive system coupled to a digestomic approach

Sayd, T.¹; Chambon, C.²; Torrent; A.³; Blinet, S.¹; Theron, L.¹ and Niderkorn, V.¹

¹INRAE, UR370 Qualité des Produits Animaux, F-63122, Saint Genès-Champanelle, France
²INRAE, Plateforme d’Exploration du Métabolisme Composante Protéomique (PFEMcp), F-63122, Saint Genès Champanelle, France
³Université Clermont Auvergne, INRAE, VetAgro Sup, UMR Herbivores, F-63122 Saint-Genès-Champanelle, France

Key words: protein digestion; tannins; rumen; abomasum; sheep

Abstract
Improving the use efficiency of dietary protein in ruminants is a major challenge to decrease feed supplementation and significantly decrease nitrogen (N) losses to the environment. The aim of this study was to characterize the effects of tannins on protein digestion in the rumen and in conditions simulating the abomasum, using a dynamic in vitro digestive system coupled to a digestomic approach. Three ruminally-cannulated sheep fed with alfalfa hay were infused daily with a solution of tannins, while three other sheep were infused with water (control). Standardized ruminal fluid was introduced into the digester, which simulated the transit of digesta under physicochemical conditions mimicking the abomasum in terms of pH regulation, digestive enzyme infusions and transit rate. Protein degradation in the rumen and in the simulated abomasum was analyzed by determination of fermentation end-products, and identification and quantification of peptides (Label Free Quantification) by LC-MS/MS high resolution (Orbitrap). The analysis of rumen samples showed that tannins result in a clear decrease of fermentation end-products related to protein degradation, namely ammonia (NH₃) and iso-volatile fatty acids (VFA), and a greater abundance of the Rubisco, a major plant protein. In the simulated abomasal compartment, the peptidomic analysis showed that the hydrolysis intensity of Rubisco was higher in the presence of tannins compared to the control group. These results indicate that protein-tannin complexes could be dissociated in the physico-chemical conditions of the abomasum, increasing the flow of peptides to the intestine after protection of protein by tannins in the rumen.

Introduction
Improving the efficiency of dietary protein use is a major challenge for the development of more efficient and sustainable ruminant production systems (Gerber et al., 2013). This objective requires in particular limiting the excessive degradation of protein in the rumen, to increase the proportion of nitrogen (N) digestible in the intestine and reduce the N losses through urinary release into the environment. A potential solution is the use of tannins, which are able to form complexes with protein, partly protecting them against rumen degradation (Patra and Saxena 2011). However, the fate of nitrogenous compounds in the whole gastrointestinal tract, which may condition a potential increase in N absorbed, remains largely unknown. The objective of this study was to characterize the effects of a tannin extract on the dietary protein digestion in the rumen and in conditions simulating the abomasum, which is the first post-rumen digestive compartment, using an original and dynamic in vitro system coupled to a digestomic approach using high resolution mass spectrometry.

Methods and Study Site
The experiment was conducted at the INRAE Clermont Auvergne Rhône-Alpes centre in France. The experimental procedures were conducted in accordance with the European Union Directive

The abomasal digestion of proteins was analyzed by introducing ruminal fluid into an in vitro dynamic system. Two treatments were applied, for which proteins were i) partly protected from ruminal degradation by the addition of tannins, which are compounds complexing with proteins to reduce their solubility or ii) normally digested in the rumen.

For two weeks, six sheep equipped with a rumen cannula were fed only with 1.5 kg/day of alfalfa (Medicago sativa) hay (in g/kg dry matter, organic matter = 903, crude protein = 135, neutral detergent fibre = 484, acid detergent fibre = 345). Every day before afternoon feeding, three sheep were infused through the cannula with 500 ml of a solution containing 100 g of a tannin extract from quebracho and chestnut tree species (Silvafeed® ByPro, Silvateam, San Michele Mondovi, Italy) (treated animals), while the three other sheep were infused with water (untreated animals, control). After these two weeks, for each sheep, digesta were taken from the rumen before the morning feeding, roughly filtered so as to standardize the particle size, and then the ruminal fluid was introduced into the digester (DIDGI®, INRAE, Paris, France) described by Ménard et al., (2014). To mimic the abomasal compartment in terms of regulation of pH, infusions of acid and digestive enzymes and transit rate, the following conditions were applied: The initial mix was constituted of 60 ml of simulated gastric fluid (pepsin, 602 U; lysozyme, 300000 U) and 40 ml of rumen fluid. The pH was adjusted at 2.5 with HCl. The flux of rumen fluid entering the abomasal compartment was set at 2.5 ml/min during 60 min. Two pumps were used to automatically regulate the pH at 2.3 with HCl and infuse an enzymatic mix (pepsin, 520 U/min; lysozyme, 750 U/min) into the compartment.

The digestomic approach was developed by sampling rumen fluid at the input of the digester for proteomic analyses, then regularly sampling the simulated abomasal compartment for pepitomomic analyses. For the rumen samples, fermentation end-products related to protein digestion (total and iso-volatile fatty acids (VFA) and ammonia (NH₃)) were determined. Rumen proteins were extracted from the SDS-PAGE band and treated for proteomic analyses as described by Théron et al., (2014). Peptides resulting from protein digestion in simulated abomasum were identified by high-resolution mass spectrometry (LC-MS/MS Orbitrap) and quantified by label-free using Progenesis QI software (Waters), as described by Sayd et al., (2016). For quantification, only peptides with a sequence shared by a single protein were used for the calculation of abundance. Thus, the abundances of each single peptide for a protein were summed to give the abundance of the protein in the sample. The protein abundance was then used to assess the intensity of protein hydrolysis during digestion. Principal component analysis (PCA) of the Tannin and Control samples was applied at different kinetic points after 15 (A15) and 60 (A60) minutes of digestion in the abomasum, and confidence ellipses were calculated using R. Data of rumen fermentation parameters were analyzed with R using a mixed linear model that included the fixed effect of tannin infusion and the random effect of animal donor of rumen fluid.

Results

The analysis of rumen samples as introduced in the digester showed that concentrations of total VFA, iso-VFA and ammonia were significantly lower in sheep infused with tannins than in control sheep ($P < 0.001$, Figure 1).

**Figure 1:** Rumen fermentation end-products related to protein digestion (total volatile fatty acids (VFA), isobutyrate, isovalerate and ammonia (NH₃)) in sheep fed with alfalfa and ruminally infused with a tannin extract (Tannin, grey bars) or with water (Control, white bars). ***$P < 0.001$.**
The proteomic analysis of rumen fluids resulted in the identification of 20 *Medicago* proteins, based on 169 peptides, of which 140 were unique. Among these proteins, 5 showed differential intensities when comparing rumen fluids from sheep infused with tannins vs the control sheep ($P < 0.01$), with a fold change of approximately 5. Two Rubisco chains [Ribulose bisphosphate carboxylase small chain (rbcL and RBCS)] were identified with higher intensities in the rumen fluid from sheep infused with tannins, and 3 proteins involved in metabolism (HSP70-1, Rab and UBQ11) were identified with higher intensities in control rumen fluid ($P < 0.05$). These differences in protein intensities explain the separation of both groups as shown by the PCA (Figure 2). The projection according to the first two dimensions (61% and 29% of variance supported by the dimensions 1 and 2 respectively) clearly differentiates the rumen fluid of sheep infused with tannins from the control animals.

The peptidomic analysis of simulated abomasum from both groups resulted in the identification of 30 *Medicago* proteins, based on 575 peptides, of which 363 were unique. Differential intensities were found for 19 proteins ($P < 0.05$). Eight proteins were identified with higher intensities in the tannin group, with fold change ranging from 2 to 9, among which Rubisco chains (rbcL and RBCS) and ATP synthase (atpA and atpB). Eleven proteins showed higher intensities in the control group, with fold change of approximately 2, among which were membrane proteins (psaB, psaA, psbD, petB, psbA, petA, psbB and psbC). These differences can be observed in the PCA (Figure 2) where both tannin and control groups are separately projected according to the first two dimensions (with 60.6% and 19.5% of variance supported by the dimensions 1 and 2, respectively). The results demonstrate a clear distinction based on the peptidomic analysis of simulated abomasum from sheep infused with tannins and control sheep.

**Rumen**

**Abomasum**

**Figure 2:** Peptidomic analysis of rumen and simulated abomasal fluids from sheep fed with alfalfa and ruminally infused with a tannin extract (Tannin) or with water (Control)
Discussion

As expected, the infusion of tannin extract in the rumen resulted in a clear decrease of microbial protein degradation as shown by the decrease in ruminal concentrations of isobutyrate and isovalerate, which are branched-chain VFA derived from oxidative deamination of branched-chain amino acids (valine, isoleucine, and leucine) (Allison, 1978). This outcome is reinforced by the decrease in ruminal NH₃ concentration as a result of reduction of amino acids deamination, although NH₃ in the rumen has to be considered as a pool resulting of different fluxes, namely production from degradation of nitrogenous compounds, absorption across the rumen epithelium, consumption for urea and microbial protein synthesis (Abdoun et al., 2006). Similarly, the decrease in total VFA in the rumen in the presence of tannins indicates a lower microbial activity and substrate degradation (especially fibers and protein) due to a reduction in cellulolytic and proteolytic microbes (Bodas et al., 2012). The proteomic analysis of rumen fluid and subsequent PCA analysis showed a graphical separation of the two groups, mainly due to difference in abundance of the Rubisco (tannin group > control group), a protein representing a relevant model as it can comprise up to 50% of the total soluble protein in plant leaves or inside the microbes (Andersson and Backlund, 2008). Taken together, all our results indicate that the rumen fluid from sheep infused with tannin introduced in the digester contained protected protein through tannin-protein binding in contrast to the control group.

In the abomasal compartment simulated in the digester, the peptidomic analysis shows that hydrolysis intensity of Rubisco was higher in the presence of tannins compared to the control group. This result suggests that the Rubisco-tannin complexes could be dissociated in the physico-chemical conditions of the abomasum with an increased flow of peptides to the intestine after protection of Rubisco by tannins in the rumen. Our observations are consistent with those of Jones and Mangan (1977) showing that a lower pH facilitates dissociation of the condensed tannin-protein complex. Proteins have also been shown to be precipitated by condensed tannins most efficiently at pH values near their isoelectric points and with affinity depending on the size of protein, peptides with less than six residues interacting weakly with tannins (Hagerman and Butler, 1981) but also on tannin characteristics (Mueller-Harvey et al., 2019). In this sense, the peptidomic approach appears to be particularly well adapted as it may help to identify and quantify the type of protein hydrolyzed throughout the gastrointestinal tract according to the structure of tannins. The challenge remains to predict the quantitative contribution of tannin-bound protein to improve N supply to the small intestine. This issue is important as it may allow a significant decrease in protein feed supplementation, improving protein self-sufficiency for farmers and significantly decreasing N losses to the environment.

Acknowledgements

The authors acknowledge the financial support provided by transnational funding bodies, being partners of the H2020 ERA-net project - CORE Organic Cofund - and the cofund from the European Commission, under the project ProYoungStock “Promoting young stock and cow health and welfare by natural feeding systems”. Financial support was also provided by INRAE department ‘Animal physiology and farming’. The authors thank the staff from the Herbipole experimental unit (INRAE Auvergne Rhône Alpes) for the care of animals.

References


KEYNOTES
THEME KEYNOTE 5

Drought Management and Climate Change in Rangelands And Grasslands

Prof. Mark Howden
Biodiversity conservation and sustainable livelihoods in rangelands: Trends, challenges and opportunities

John Waithaka
International Union for Conservation of Nature (IUCN) - World Commission on Protected Areas

Key words: Biodiversity, conservation, protected areas, rangelands, sustainable livelihoods

Abstract
Rangelands cover about 54% of the earth’s surface and are important for agricultural and livestock production, environmental protection and for the in-situ conservation of genetic resources. Despite providing services that support life on earth, rangelands have been neglected to a large extent when compared to other types of ecosystems. This paper provides an overview of the importance of rangelands in conserving biodiversity and supporting the livelihoods of millions of people globally. Rangelands have lost ecological integrity due to unsustainable anthropogenic land use changes and impacts. It is estimated that over 80% of Key Biodiversity Areas (KBAs) are either not adequately protected or not protected at all. The rangeland ecosystems constitute over 43% of KBAs covered by terrestrial protected areas globally. The biodiversity-agriculture nexus show that Agriculture is the leading driver of global land-use changes and biodiversity loss accounting for up to 80 per cent of biodiversity loss, up to one-third of greenhouse gas emissions, and use up to 70 per cent of freshwater (UN 2021). Given the importance of rangelands and the threats they face, their conservation must be made part of policy discussions around everything from confronting climate change to reducing poverty, managing threats to biodiversity, and developing sustainable food systems. Investment in landscape restoration interventions to improve ecosystem services such as pollination, better water quality or soil fertility must become issues of high priority in rangelands.

Introduction
Rangelands cover a large portion of the earth’s surface and are important for agricultural and livestock production, environmental protection and for the in-situ conservation of genetic resources. Rangelands also contain some of the earth’s most precious habitats that conserve biodiversity and deliver crucial ecosystem service. In both developed and developing countries, millions of people depend on rangelands for their livelihood. Despite providing services that support life on earth, rangelands have been neglected to a large extent when compared to other types of ecosystems (Johnsen, et.al, 2019). For example, just 10 per cent of national climate action plans (as part of the Paris Climate Agreement) include references to rangelands, compared to 70 per cent of those plans including references to forests (International Livestock Research Institute- (ILRI) et al, 2021).

Changes in rangelands
According to a recent Rangelands Atlas published in May 2021, rangelands cover 54% of global
terrestrial surface and are made up of several rangeland types, including deserts, grasslands, forests, shrublands, woodlands, and tundra. Grasslands make up 23% of global terrestrial surface and 44% of rangelands (ILRI 2021).

The ILRI et al 2021 Report shows that rangelands have undergone a critical transition from mostly wild to mostly anthropogenic between 1700 and 2000, passing the 50% mark early in the 20th century. Within this period, for example, pastoral villages grew from 1,566 km² to 365,064 km² (23,300% increase); populated croplands grew from 287,308 km² to 4,010,017 km² (1406% increase); populated rangelands grew from 1,101,217 km² to 11,209,691 km² (1017% increase); irrigated villages increased from 10,054 km² to 695,705 km² (6929% increase); remote croplands increased from 8,311 to 1,991,376 km² (23961% increase) and residential rainfed croplands increased from 873,040 to 4,274,271 km² (4900% increase).

These changes have resulted in intense resource use conflicts and biodiversity loss, in most cases fueled by poor governance, ineffective legislation, poor land use planning, conflicting land use policies, burgeoning human population growth, unplanned developments, poverty, overlapping land use rights, value conflicts, economic inequality, among other causes. A recent biodiversity assessment shows that the global populations of mammals, birds, fish, amphibians and reptiles declined by 68% between 1970 and 2016 (Almond et al, 2020), while another report estimates that one million animal and plant species are threatened with extinction, and predicts that 550 mammal species will be lost this century, including within rangelands, if we continue along our current path (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2019).

Threats to global biodiversity in the Key Biodiversity Areas (KBAs), defined as sites that contribute significantly to the global persistence of biodiversity, has continued to escalate. Over 80% of KBAs are either not adequately protected or not protected at all. In areas where biodiversity is managed by indigenous and local communities, threats from tenurial insecurity, extractive industries and inappropriate developments, imposition of inappropriate land uses, industrial agriculture, internal inequalities and injustices, demographic and cultural changes, and the incursion of external markets are contributing to biodiversity loss. Without security of tenure and active participation in decisions that affect them, it is impossible for such communities to effectively protect their lands and resources (Gonzalo et al (2005).

Protected areas

One of the most effective global strategies to achieve the long-term conservation of nature and the associated ecosystem services and cultural values has been the establishment of protected areas. By October 2021, there were 266,561 protected areas in 245 countries covering more than 22.5 million km² (16.64% of land) and 28.1 million km² (7.74% of coastal and marine areas) (https://www.protectedplanet.net/en). Within rangelands, protected areas constitute over 43% of the area covered by terrestrial protected areas globally.

Besides conserving biodiversity, effectively managed protected areas can be crucial players in poverty reduction, employment and wealth creation. Through the provision of ecosystem services, they also support many sectors of the economy such as energy, water, agriculture, security, forestry and horticulture.

Many studies show that most protected areas are not effectively managed and are not achieving their conservation and sustainable development goals (e.g., Leverington et al, (2010); Knights et al (2014); Lindsey et al., (2017); Davis et al (2001); Mascia & Pailler (2011); Mascia et al., (2014); Gibson(1999); UNODC (2016); Makochechanwa, (2013), Hartley et al (2007), Lindsay et al (2018).

Since the 2003 Durban Accord (IUCN 2005), protected areas have been increasingly viewed as social enterprises that should be managed with the needs of local communities in mind, often in partnership with local communities. In addition, community-conserved areas have been created and/or recognized. The drivers of change behind the modern model of protected areas include a heightened awareness of human rights, including through international mechanisms such as the 2007 United Nations Declaration on the Rights of Indigenous Peoples (UN 2007) and a greater move toward democratization. Communities and private land owners have set aside conservancies to create space for wildlife while providing wildlife-focused development options that enable landowners to adapt to the changing socioeconomic realities. In areas where animal husbandry and agriculture are failing to deliver reliable returns due to shifting weather patterns, conservancies are part of an alternative land-use model that can reduce rural poverty and generate alternative revenue streams. In Kenya, Namibia and Zimbabwe, for example, conservancies have provided strong, tangible benefits beyond purely conservation goals - including peace, security and social cohesion (King et al 2016).
Communities are also exploring the potential for promoting biodiversity-based enterprises such as carbon trade, biodiversity off-sets, payment for ecosystem services, bioprospecting, agroforestry, aquaculture and nature-based products such as honey and drugs. Where properly designed and managed, such enterprises can help diversify resource dependent livelihoods and keep people away from pursuing unsustainable resource exploitation approaches. Bishop et al (2008) provide examples of biodiverse-based enterprises, including opportunities and challenges that are likely to be encountered.

**The biodiversity-agriculture nexus.**

Agriculture is the leading driver of global land-use changes and biodiversity loss (IPBES 2019). Recent reports have found that food systems are contributing up to 80 per cent of biodiversity loss, up to one-third of greenhouse gas emissions, and use up to 70 per cent of freshwater (UN 2021). Since 1970, the collective biomass of wild mammals has declined by 82 per cent and a small number of farmed animal species (mainly cows and pigs) now dominate global biomass, together accounting for 60 per cent of all mammal species by mass, compared to 4 per cent for wild mammals. Animal farming now occupies 78 per cent of agricultural land globally (Bar-On et al 2018). Currently, cropping and animal husbandry occupy about 50 per cent of the world’s habitable land (Ritchie and Roser, 2019) and about 52% of all land used for food production is moderately or severely impacted by the loss of healthy soil. A study on 8,688 species on the UN Red List found that 72% of species are imperiled by overexploitation while 62% of species are imperiled by agricultural activity (Maxwell et al, 2016).

Global consumption through exportation of agricultural products increased by 2800% between 1970 and 2017 (Liu 2020). The 2021 UN Food Systems Summit Processes have shown that the current production systems are unsustainable and must be rethought for better health of people, environment and to deal with poverty.

In addition to food production, food preparation is another factor that must be addressed to lessen loss of biodiversity and ecosystem services in rangelands. Of all the wood produced every year in sub-Saharan Africa, 90 percent is used as fuel, posing a major sustainability challenge (FAO 2021). Environmental damage from fuelwood harvesting is significant where too many people depend on too few and diminishing forests and woodlands. Innovations to replace wood fuel with a more sustainable source must become an important agenda in national and local efforts to conserve biodiversity.

The IUCN is developing a new engagement in agriculture, guided by the vision of a future where biodiversity is restored and conserved on farms and in agricultural landscapes as nature-based solutions to global challenges and human and societal needs, contributing to the transition towards sustainable and resilient societies (IUCN 2021).

**Discussions and conclusions**

Given the importance of rangelands and the threats they face, their conservation must be made part of policy discussions around everything from confronting climate change to reducing poverty, managing threats to biodiversity, and developing sustainable food systems. Transforming our food and agricultural systems hold the power to realize our shared aspiration for a better world.

Investment in landscape restoration interventions to improve ecosystem services such as pollination, better water quality or soil fertility must become issues of high priority in rangelands. Such efforts will not be realised at a meaningful scale without the buy-in of millions of indigenous and local communities, farmers, agribusinesses and governments. Acting collectively, we must encourage, facilitate, and deliver rangeland conservation and restoration policies and investment that harness and capture indigenous knowledge to deliver meaningful local development and sustainability. Uplifting the living standards of indigenous peoples must be an important step in addressing the biodiversity problem.

Systemic challenges such as overconsumption, high population growth, agricultural and economic systems that do not value biodiversity; low levels of investment in conservation; weak policies; inequalities; conflicting land use policies and low public awareness of the importance of biodiversity must be addressed. Equitable governance of nature, capacity building, economic empowerment of indigenous and local communities, equitable sharing of the costs and benefits of nature, and rights-based approaches to conservation must be embraced if there will be any hopes of reducing human impacts on biodiversity in rangelands. In addition, political will remain a key success factor in achieving conservation outcomes that are grounded on the principles of equity and inclusivity.
References


Lindsay P, Jennifer R. B. Miller, Lisanne S. Petracca, Lauren Coad, Amy J. Dickman, Kathleen H. Fitzgerald, Michael et al. (2018). More than $1 billion needed annually to secure Africa’s protected areas with lions. PNAS November 6, 2018 115 (45) E10788-E10796.


HEME KEYNOTE 7
PASTORALISM, SOCIAL, GENDER, AND POLICY ISSUES
Nahid Naghizadeh, Member of the Board, CENESTA, Iran
Member of the UNCCD CSO Panel for Asia

Key words: Pastoralism, Territories of life, Recognition

Introduction
Nearly half of the Earth’s land surface is classified as rangelands. Rangeland’s health and productivity are directly critical to the livelihoods, cultures, and resilience of more than 500 million people worldwide, many of whom are indigenous peoples who depend on rangelands. Pastoralism is very diverse; it can be found in all continents, from the drylands of Africa and the Arabian Peninsula to the highlands of Asia and Latin America, or the tundra in the circumpolar zones, and in particular where crop cultivation is physically limited. Pastoralism supports several hundred million households worldwide and manages one billion animals, including camels, cattle, sheep, goats, yaks, horses, and reindeer, contributing more than 10% of the world’s meat production and the large portion of dairy products, wool, leather, handicrafts, and other byproducts. Pastoralism produces food and ecological services and is often the only significant economic contribution in the world’s poorest regions, and is the cultural backbone of longstanding civilizations.

As the late Dr. Mohamad Taghi Farvar1 regularly noted, “The migratory practices of indigenous peoples are almost always de facto nature conservation strategies.”

A growing number of researchers and practitioners documented that Pastoralists are the Backbone and Invisible Assets of the World’s Drylands. In addition, there is increasingly robust evidence that pastoralism is a viable and sustainable livelihood and productive system, managing uncertainty, and risk in diverse arid land ecosystems. In addition, there is ample scientific evidence that pastoral systems based on mobility and livestock diversity support a healthy ecosystem and complement other land uses such as wildlife conservation.

Pastoral women are key agents in socio-cultural and economic development, conservation, and management of natural resources. In most pastoral societies, women face more challenges linked to property rights, decision-making processes, and socio-cultural aspects.

Build on this vision, the history of conservation by indigenous peoples and local communities, including mobile pastoralists, goes back thousands of years and is based on their strong social organization, identity, collective production, and adaptation of their customary governance and management systems to complex ecological conditions in rangelands and grasslands of fragile ecosystems. Pastoralists have co-evolved over millennia with rangelands and grasslands», and this refers to the fact that grasslands and rangelands are «grazing dependent» and will deteriorate if all grazing is taken off. These are collectively referred to as “territories and areas conserved by Indigenous peoples and local communities, or

more simply, “territories of life”, A globally applicable governance type for areas and territories under customary management.

Pastoralists are multifunctional, and they generate diversified sources of income and contribute to sustained natural resource management because they intertwined their cultures, identities, and ways of life, they produce food in the harshest environments despite the lack of recognition and support from state governments and others in powerful positions in today’s society.

These shreds of evidence show how pastoralism provides many hidden benefits that are not included in statistics and how this absence of true values fuels the marginalization of pastoralists and encourages policies that erode the sector and traditionally suffer from being poorly understood marginalized excluded from policy dialogues.

Policy and Social Issues

The indigenous mobile pastoralists have traditional customary systems and practices with unique rules, regulations, spiritual beliefs, and relationships that guide the governance and stewardship of their territories of life. These systems have been forced to face issues that threatened their very existence in the recent past. Chief among these threats are two: the induced weakening of the social governance systems and the resultant fragmentation of pastoralists’ territories of life due to generations of marginalization and exclusion from decision-making processes that affect them, dispossession from territories, and cultural practices. These have, in turn, tended to result in various social issues and erosion of the socio-ecological integrity of their territories.

Despite the existence of robust evidence, most policy and decision-makers have preconceptions about pastoralists’ importance as a land-use system, believing it to be economically inefficient and environmentally destructive. Actually, in addition to the climatic tensions of drylands, the said preconceptions are the root of significant excuses for designing, approving, and implementing a series of inappropriate policies and programs. These policies are not in harmony with the socio-economic and ecological features of pastoralists and increased various types of pressures threatening their territories of life in the recent past.

In other words, pastoralists well-conserved their territories before the massive interference and domination by government policies, at least since the early twentieth century, and later by the private sector. In this background, in addition to using the existence of “Free Prior Informed Consent” or any other available tools to recognize and defend the rights of Indigenous Peoples, there need more assertive and proactive approaches such as self-determination, self-governance, and recognition of collective territories and cultural practices to secure the fullness of territories and cultures against specific threats that consistently undermined drylands ecosystems and pastoralists.

The following diagram represents a general problem tree of social and policy issues of pastoralists and rangelands.

---

General Problem Tree of Social and Policy Issues of Pastoralists and Rangelands

The diagram shows how mobile pastoralism is increasingly under threat from legal, economic, social and political disincentives and barriers to mobility of livestock including rangeland degradation. The ultimate drivers of rangeland degradation are typically associated with policies, socio-economic changes, or interactions of socio-economic and governance factors with climatic stressors, such as drought. In a nutshell the poor & inappropriate policies & programs are the root cause of the fragmentation of pastoralist territories—undermining their Mobility and survival.

Gender issues

The role of women among pastoralists has been much discussed, and it is agreed that “Empowering women in pastoralist communities is to empower future generations of pastoralists.” Gender Equity is one of the main elements and pillars of sustainable pastoralism. Therefore, addressing gender issues through a collective and bottom-up approach while retaining pastoralist society’s culture and traditional lifestyle.

In most pastoral societies, women face more challenges linked to property rights, decision-making processes, educational opportunities, water shortage, energy, health issues, and even food in a climate crisis. Such inequalities affect their role and responsibilities, restrict women’s development potential, and limit their opportunities for self-strengthening in various aspects, in particular within the socio-economic growth of the entire family.

Pastoral women play a key role in different aspects within pastoral communities, including indigenous food production systems, mainly processing dairy products; livestock keeping (in particular, newborn ones, grazing, feeding, milking, and sheep shearing); producing handicrafts; Treating animal disease (traditional & modern); managing poultries and their byproducts; supporting community during seasonal migration (packing and unpacking the stuff); maintaining the family cohesion in different aspects; managing family diet in terms of cooking and washing and conservation and sustainable use of medicinal and edible plants.

In fact, despite many challenges, Pastoral women are key agents in cultural and socio-economic development and conservation and management of natural resources. In addition, pastoral women have been active participants in global policy dialogues and relevant gatherings in various regions, highlighting their role in achieving
sustainable pastoralism.

Therefore, pastoral women need to strengthen their position in various socio-economic aspects, including property rights, decision-making, use and control of income, assets, resources, and services. It is important for women also to be part of the community processes of adapting and responding to changes as women have a crucial role in helping adapt to changes, which might entail other changes within families and communities.

Conclusion

For centuries mobile pastoralism has adapted itself to the environment and regulated migration in search of water and feed, so it is said that mobile pastoralism is the most viable and resilient form of production and land use in most of the world’s fragile drylands. In this context, the world is responsible for thinking profoundly and wisely towards a fundamental change and considering pastoral communities’ dynamic and viable socio-economic and ecological systems and values. A Paradigm Shift is needed towards Sustainable Pastoralism and sustainable use, conservation, and restoration of rangelands and grasslands. We need to halt drivers of biodiversity loss and marginalization of Indigenous peoples, both in direct and indirect ways, to stop harmful industries like mega-infrastructure, unsustainable consumption, growing inequality, and climate breakdown.

Mobile pastoralists identify themselves by their ancestral territories, including summering and wintering territory and the migratory routes, with no regard to administrative and political boundaries. In other words, mobility, territory and, right to land are the basis of pastoralists’ social identity and livelihoods. In the last decade, Territories of life have gained significant recognition by IUCN, CBD, UNESCO, and other international policy instruments. Still, there are huge gaps. Most countries have no or very inadequate legal and policy mechanisms to recognize territories of life as a crucial missing link to put the indigenous mobile pastoralists as the primary agents to conserve their bio-cultural diversity within their territories.

Recognition of pastoralists’ tenure and property rights with particular attention to women’s right to land in the framework of gender equality (as one of the ten implementation principles of the Voluntary Guidelines on the Responsible Governance of Tenure) is a necessary change benefit rangelands and pastoralists society. Empowerment and strengthening the role of pastoral women to establish self-organized and locally adapted funds and institutions to address gender issues and equity is necessary to meet gender-responsive policies and programs and improve pastoral women position in various aspects, including property rights, decision-making, income, and wealth generation activities, and access to resources and services. Provision of proper and locally adapted mobile social services, plus institutional and financial support to motivate and encourage pastoralists’ youth (male and female) to engage in pastoral livelihoods and continue pastoralists’ way of life, needs extreme attention to sustaining the pastoralists systems and sustainable land management.

Even though the policies are inappropriate and unbalanced, they can be fixed as long as governments understand the tremendous contribution of pastoralism to GDP and see that sustainability will require changing paradigms. Therefore, we call for Multi-stakeholder alliances to approve the IYRP to raise awareness and fill knowledge gaps globally about the value of healthy rangelands sustainable pastoralism, supporting pastoralists to document and communicate their perspectives, experiences, knowledge systems, and science - as mainstream research/science are biased against mobile pastoralism.

Let us remember and renew our promise to leave no one behind toward conservation, sustainable use, and restoration of rangelands and grasslands through strengthening, recognition, and involving the pastoralists society and their governance institutions for their actual participation in decision-making and policy-making process linked to their destiny at all levels.
References


CONCURRENT SESSION 6

THEME 1. RANGE/GRASSLAND ECOLOGY

Topic: Commons: Old, Current and Future Challenge for Rangeland
What Innovations In Collective Issues to Face These Challenges
Collaborative construction of a method that contributes to improve the decision making in associative ranches by controlling the grass allowance in a context of climate variability

Emilio Duarte Esteves 1, Rómulo Cesar 1, Javier Fernández 1, Marcelo Ghelfi 1, Valentina Herrera 1, Virginia Caravia 2, Rodrigo Iribarne 2-4, Federico de Brum 3, Héctor Rodríguez 3, Marcelo Pereira Machín 1

1 Instituto Plan Agropecuario 2 Hired technicians 3 Instituto Nacional de Investigación Agropecuaria 4 Facultad de Agronomía 5 Instituto Nacional de Colonización

E mail: eduarte@planagropecuario.org.uy

Abstract
Pasture management and the particular conditions of each year are responsible for productive results, farm income, and condition of the pasture. A simple and robust method that relates the available grass and the required grass was built in a participatory manner, and contributes to a critical reflection process among the group of decision-making, adapting to their context. In 17 farms from the Basalt region in Uruguay, grass and animals were monitored seasonally. A simple method was developed with farmers, and from it offer needed to meet production targets (Kg MS/Kg PV) the amount of grass required was calculated. The grass height was measured with a ruler in order to obtain the available grass. From the relationship between the available grass and the necessary grass, a situation index (ISPC- Index on the food plate) was developed, and ranges were established with colors. Index less than 0.6 with Red color, between 0.6 and 0.8 Yellow, between 0.8 and 1.2 Green, and greater than 1.2 brown. Each group of ranchers analyzed their seasonal index together in workshops with other ranchers and guest technicians, who proposed alternatives to place the index within the optimum range. The host ranchers group selected and ordered the proposed alternatives by priority, and the resulting actions were described by using Unified Modeling Language (UML) diagrams. Each rancher obtained one UML per season, with the right action to be taken in case of deficit or excess of grass. This process incorporated local, professional and academic knowledge, and by applying a simple method, measures were adapted according to the context of each rancher. The technician role was to facilitate the process by creating an environment that stimulated critical reflection, supported by real evidence. Participating ranchers achieved the ability to measure, relate, discuss and decide, and significantly improved their productive results by adopting participatory constructed methodology.

Introduction
Uruguay is a livestock country. It has the highest number of beef cattle (3.4 animals) and the highest consumption of meat (120 Kg) per capita in the world. Breeding systems are mostly using the natural pasture, and are located in areas that are vulnerable to a water deficiency (Cruz et al., 2014). Droughts are common and their impact on primary and secondary production is significant affecting physical and economic outcomes, and the trajectory of farmers and their families (Bartaburu et al., 2015). The most commonly used indicator in Uruguay to define the number of animals that can graze on a field is the Livestock Unit (UG) referred to as endowment. This allows a value in total livestock units at a certain time to be obtained. By dividing the total UG by the total area, you get the endowment, in UG/ha. The limitation of this method is that it references animals (UG) with surface area, but without describing the ability of actual grass. Do Carmo et al., (2019) concludes in his work that the control of the fodder offer improved the results, but identified limitations in adoption, and highlighted the need to involve farmers in discussions on proposed changes as well as monitoring. The lack of decisions in a timely way about the grass supply, causes the particular conditions of each year explain much of the productive results, property income, and condition of pasture, Soca et al., (2009). This statement is proven, and food mismatch situations can be observed due to the effects of climate variability affecting grass growth, such as lack of decisions in a timely way to adapt to these variable situations.
Participatory construction of a method that includes; monitoring grass and animals, diagnosing the forage situation, arguing on the basis of evidence, and facilitating decision-making to adapt to situations as variable as it is uncertain, will help lift important constraints on livestock systems, especially in associative systems, where decision-making is more complex.

**Materials and Methods**

The monitored farms were selected in the Basalt Region, where the RLN del IPA has influence on IPA, an extension institution, implemented the project, in collaboration with research institutions (INIA and FAGRO), development (MGAP and INC) and 9 farmers organizations. Reference grounds were initially developed; 10 individual management and 7 associative management. The 17 ranches are mostly breeders, all have cattle, some sheep and have different surface.

Workshops were held to level knowledge and the monitoring protocol was developed. Monitoring began in spring 2017 and culminated in winter 2019. In the summer of 2017/2018 rainfall was below average, while in summer 2018/2019 above average.

Monitoring was carried out for 2 years in all 4 stations. The grass height was measured with a ruler for availability. The animal’s weight was obtained with balance, and the demand for grass was defined according to the animal category (rearing, grazing and wintering) and production objectives. Based on the relationship between total available grass (Kg MS) and total required grass (Kg MS), an index was developed, which ranchers named the Food Plate Index (IsPC). For IsPC values, color ranges were set to interpret the diagnosis. Index less than 0.6 (meant the field had less than 60% of the required grass), Red indicating “danger”, between 0.6 and 0.8 Yellow “caution”, between 0.8 and 1.2 green “optimal”, and greater than 1.2 Brown “excess of grass”.

The seasonal IsPC obtained on reference grounds was analyzed together with other ranchers and guest technicians, in seasonal workshops, where alternatives were identified to place the IsPC within the optimal range. Subsequently, the host rancher selected, supplemented and ordered the proposals by priority. Strategies to control the offer of fodder (animal sales, supplementation, etc.) were described using UML diagrams, easily interpreted. Finally, different strategies were applied for the escalation of the built method; (a) field days where the monitored producers tell other ranchers the method used and results obtained, b) predial accompaniment to new stakeholder groups, c) training courses to producers and d) dissemination in articles, seminars, congresses, etc.

For the evaluation device, questionnaires were designed for ranchers who assisted in workshops, conferences, accompaniments and courses, and forms for external technicians and team members.

**Results**

It was possible to develop necessary fluidly reference fields. In a participatory way, a simple method was developed to measure grass and animals, and producers acquired the ability to measure.

Seasonal monitoring was carried out and the IsPC that related the grass available in grassland with the grass required by animals was built, and was used to diagnose the forage situation. Figure 1 shows average values for the group of ranchers, measured grass height, required grass height, and IsPC.

![Figure 1. Measured grass height, required grass height, and IsPC](image)

From workshops, a decision diagram (UML) was built for each site containing the actions to keep the IsPC within optimal range.
Regarding the workshops, expectations were met for all participants, there were no negative responses. Methodological aspects were highly valued as an educational extension tool, most participants evaluate between good and excellent the possibilities; contribute, learn, know the experiences of others, raise doubts with technicians and/or producers, motivate yourself to apply what you have learned, join with others to do things in common, and engage with others for friendship purposes. More than 90% of attendees noted that they learned new things or have new ideas (reflections on things they already knew) and stated that they want to apply it. All participants say they talked to other neighbors about it in the workshops (between 3 and 10).

In training courses and farm conference (escalation) surveys were conducted by consultation on; the practicality of the method to quantify the grass on the property and the demand for grass by animals, and the usefulness of the IsPC to make decisions on the premises, and for all questions 100% is between Excellent, Very good and good, there are no negative assessments (Bad, Very Bad).

Discussion
A simple and robust method was built in a participatory manner that related two important variables; the available grass, the required grass, and from its relationship (IsPC) critical reflection was facilitated among farmers (Discussion Workshops) to suit each context (UML). The reference grounds were strongly involved in the development, application of the methodology and improvement of the results.

Ranchers who were invited to participate in workshops, farm conference and training courses expressed a desire to apply what they learned on their premises, indicating a favorable a priori evaluation (by the technique learned of grass measurement and/or by the decisions viewed from the application of the technique). We can conclude that to make decisions it is necessary to monitor or measure. The variable grass height is very robust for the information it provides, and is very simple to obtain, an important feature when it comes to implementing it.

Finding robust and simple variables was a very difficult and sophisticated task, but it was achieved from participatory work between ranchers and technicians. The objective information provided by the monitoring tool, and its relationship, allowed the participants to focus on the evidence, and avoid assumptions which move the decision-making away from the reality. It could be seen that availability of grass on the properties was variable, mainly as a result of the climate and animal load applied by each producer, and allowed to justify the results obtained. On one hand, from the evolution of the IsPC, the results achieved could be better understood and explained, and on the other hand the same ISPC acquires a forward-looking value and that justified proactive actions.
behavior that anticipated changes) in the face of future scenarios. From a simple indicator, IsPC, but with a lot of technical content, it was possible to diagnose whether the grass available was sufficient based on animal requirements, which allowed reflection among the participants. The resulting methodology is being applied in different escalation strategies, training, group accompaniment (in agreement with INC) with excellent evaluation by producers, and its use as a tool in new extension projects was planned.

References


Collective Approach of Rural Development: Case Study of “Maronna Foundation” in the Pampa Bioma, Rio Grande do Sul, Brazil

Vargas, Adriana Ferreira da Costa1; Silveira, Vicente Celestino Pires2

1Fundação Maronna; 2Universidade Federal de Santa Maria

Key words: Governance; APA do Ibirapuitã; Family farmers.

Abstract
The Maronna Foundation was created in the 1980s by two brothers who were heirless farmers. After a visit to Massey University, New Zealand, they decided to use their fortune to support rural farming in the Brazilian Pampa through an agropastoral institute. Over the last four decades, the foundation has developed diverse research, education, and extension projects in partnership with local, regional, national, and international institutions, especially universities, research centers, non-governmental organizations and local governments. Recent surveys conducted in the area of the Maronna Foundation demonstrate the interest of local breeders in technologies applied to farming systems, mainly for rangeland and grassland management, cultivated forages, animal genetics and herd production improvement. Such interest has been linked to the actions carried out by the Maronna Foundation over the years, as has been declared by local stakeholders, and has been scientifically demonstrated as planned in the NEXUS-Pampa Project. However, three characteristics should explain the situation: the philosophy of the Maronna Foundation that focuses on a collective approach to local growth and development; management led by a large, diverse and representative board; and practices based on both scientific competences and participatory methods. The “Rincão do 28” association of family farmers could be used as a case study of this philosophy.

Introduction
The Maronna Foundation is a nonprofit, Non-Governmental Organization, formed on August 26, 1983, through the testaments of Potito and Francisco Maronna. It is located in the Brazilian portion of the Pampa Biome, in the municipality of Alegrete, state of Rio Grande do Sul. As a testamentary foundation, it should perform and fulfill the wishes of its founders: to organize in the “Estância do Vinte e Oito” an Agropastoral Institute, similar to Massey University in New Zealand, and to manage a specialized library. Along the years, its goals were outlined as:

a) To defend, preserve and protect the environment, and to promote sustainable development;
b) To promote economic and social development and to fight poverty;
c) To undertake non-profit experimentation of new socio-productive models and alternative systems of production, commerce, employment and credit;
d) To carry out studies and research, develop alternative technologies, and to produce and promote information and technical and scientific knowledge pertaining to farming activities.

Two rural properties are part of the Maronna Foundation: Centro de Validação Tecnológica Capivari (CVT Capivari) and Estância do 28, both of which generate part of the financial resources required to maintain and promote the actions needed for achieving its goals.

CVT Capivari is located on BR-290, 12 km from the municipality of Alegrete-RS and spans an
area of 101.7 ha. It has consolidated itself as a Technologic Validation and Training Center, by offering courses and putting projects together. It maintains production as its main source of income: finishing cattle and milk production are its main activities.

The production systems are interconnected with the technologic validation and training projects, which offer internships for students from universities, institutes, and technical schools. The results are shared in field days and are also published in scientific papers. The productive system is used as a means that generates economic resources, data and information for the technicians and local farmers.

Estância do 28 is located 60 km south of Alegrete-RS, in a region called Rincão do 28, 4th subdistrict of Vasco Alves. It is inside the Ibirapuê Environmental Protection Area, which is a 318,000 ha protected area managed by ICMBio, in the municipalities of Alegrete, Quaraí, Rosário do Sul and Santana do Livramento. The property spans an area of 2,381 ha, beef cattle is the main economic activity, and natural pasture is the main source of cattle feed. The soil and terrain are varied, and affects the quality and productivity of the farmland.

In the region surrounding it, there are many farmers that had practically no prior technical support. The Rincão do 28 community is formed mostly by small rural properties classified as family farmers. The main productive activities are beef cattle and sheep farming, with small areas for subsistence agriculture (Vargas and Silveira, 2010). The main animal feed source is native pasture, in basalt and sandstone soils, which present considerable variation in quality and availability along the year (Silveira et al., 2006; Girardi-Deiro et al., 2006; Silveira et al., 2005), in which a very high number of animals is usually present, despite the seasonality of the production of this type of pasture. This contributes to the low rates of productivity and consequent low income. Over stocking is usually accentuated in small farming properties.

The people from the region are Gaúchos, whose origins can be traced back to the wars between the Spanish and Portuguese empires in claiming and delimiting land in Latin America. When considering sustainable management of an ecosystem, we cannot ignore the people therein, and should focus on indicating actions that can enable the survival of local cultures in a globalized world. Considering people as an important component of the agroecosystem, their permanence in the region is of vital importance to its sustainability.

Methods and Study Site

In this context, the Maronna Foundation created a project titled Desenvolvimento Sustentável do Rincão do 28 (Sustainable Development of the Rincão do 28). The project aims to contribute to the sustainable growth and development of the Rincão do 28 region and surrounding areas. The focus is on improving farmer income and the quality of life of those involved. It was created in December 2006 and launched in 2007. The first step was to call the local community, residents, and farmers to participate.

The methodology used in the project was to have farmers actively participate in defining the priority of the actions to be taken, based on monthly meetings. Initially, the farmers were invited to participate in a meeting to present the project. In this meeting, the farmers indicated which of the courses they were interested in. It was up to the Maronna Foundation and partners to make it possible for the actions that were agreed upon with the farmers to become effective, by communicating with organizations that could help to achieve the goals proposed. To this end, several institutions became involved in the projects, some more sporadically, others in a more systematic manner.

The first demands were of a social nature, mainly related to lack of access to basic infrastructure (such electricity and roads). As time passed, and after data had been collected in partnership with the University, actions of a technical nature, aiming at increasing production rates, and consequently improving economic income also came into demand.

With the group formed, other institutions foresaw actions that could be more effective. Thus, important projects were implemented alongside that community, being it the Maronna Foundation’s role to mediate and frequently execute the actions proposed by other projects. This included:

- Juntos para Competir (SEBRAE-RS, SENAR-RS, FARSUL, 2008-2009) joined the project to develop quality cow-calf production and improve farming production rates, since local production activity was raising beef cattle. The specific goals of this partnership were to implement the use of the technique of artificial insemination to genetically improve the herd and standardize cow-calf production, cultivate collaboration among farmers and organize the joint commercialization of cow-calves,
seeking to aggregate value to the product by offering higher quality on scale. The group became known for its progress as high quality cow-calf farmers.

- URB-AL III Program is an international cooperation program between Europe and Latin America, cofinanced by the European Community. URBAL Pampa Ovinos (2010-2012) is part of the URBAL Program, which provides technical assistance in sheep farming. The Maronna Foundation administered funds received from the European Community for carrying out the project.

- Juntos para Competir (2017-2019) – “Fortalecimento Produtivo e Mercadológico da Ovinocultura”. This project comprises a series of technical and management assistance services focusing on sheep farming, which is the second most important farming activity that produces family income throughout the year.

- Livestock Production Systems in the Ibirapuitã River Basin and Their Relationships with Water, Energy and Food Production - Nexus Pampa (2017-). The project adopts a transdisciplinary, participatory approach, and is limited to the Ibirapuitã river basin and the understanding of its reality resulting from the interactions between humans and nature. Drawing from this premise, we can explore the factors linked to the importance of water, energy and food, and their interrelations, according to the multidisciplinary “Nexus Water-Energy-Food” approach, that highlights that for an assessment to have long-term impact, it must be part of a wider process of involvement and should necessarily be discussed with the main interested parties and specialists (FAO, 2014).

**Discussion [Conclusions/Implications]**

The success of the “Sustainable Development of the Rincão do 28” project made the Maronna Foundation well-known, and in 2019 it was certified as an Entidade Executora Sebraetec.

In this new phase, the Maronna Foundation moves on from being an articulator between people and organizations to an organization that carries out projects of improvement of regional production chains. The projects regard beef cattle farming, sheep farming, and integration between livestock and crop farming. Recently, the Maronna Foundation also works with projects regarding milk production and olive cultivation, all of which inside the Pampa Biome.

Therefore, three characteristics should explain foundation actions: the philosophy of the Foundation focused on the collective approach of local development, the management led by a large, diverse, and representative board and the Foundation practices based on both scientific competences and participative methods.

**Acknowledgements**

The authors would like to thank the Ministry of Science, Technology and Communication – MCTIC and the Brazilian National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq) for their support through the 441428/2017-7 – Livestock Production Systems in the Ibirapuitã River Basin and Their Relationships with Water, Energy and Food Production - Nexus Pampa (Nexus Pampa) project. We would also like to thank *Juntos para Competir* program (SENAR-SEBRAE-FARSUL) for their collaboration.

**References**


Identifying land use options for networked Māori owned land blocks to deliver on collective aspirations in New Zealand

McCrossin, N; Walker, F A; Wedderburn, M.E.; Mato, R; McMillan, W

Key words: Indigenous land use, collective land, aspirations, extension

Abstract

Māori (the indigenous people of New Zealand) have many opportunities and challenges to realise the potential provided by their whenua (land), wai (water) and tangata (people) to deliver to their goals and aspirations. The challenges are old and new, including environmental constraints, governance, geographic isolation, fragmented land ownership, access to finance, and lack of appropriate skills, knowledge, and networks. Extension programmes aimed at the general primary production sector have failed to attract or retain any or many Māori participants. Landowner to landowner learning built around landowner aspirations along with collective action has the potential to inform an extension approach of relevance to Māori. Shared knowledge and scale can enable the realisation of opportunities from networked primary production assets and people. A programme of work “Māori Agribusiness Extension (MABX)” is being undertaken where clusters, a grouping of Māori-owned land blocks or agribusinesses willing to collaborate or collectivise towards a common goal or agreed outcomes, are formed to enable collective learning to build confidence to implement land use change and support decision making. This paper describes the extension model being used and gives an example of one cluster.

Introduction

Agricultural extension involves sharing knowledge, innovation, and technology to implement change toward improving farming systems. In August 2019 the New Zealand Minister of Agriculture announced an ‘Extension Service Model’ with a four-year pilot programme to support more productive and sustainable land use practice in the agricultural sector and a shift to higher value production. Māori (indigenous people of New Zealand) freehold land (MFL) is intergenerational and held in perpetuity. An estimated 80% of the 1.18 million hectares of MFL suitable for primary sector use is considered unutilised, underutilised, or underperforming. Research suggests 55% of the 1.18 million hectares has potential for improvement, providing opportunity to deliver significant benefit to Māori and to achieve government priorities (MAF 2011). Research since 2010 (MPI 2013) indicates that access to primary sector expertise, and capability development opportunities for Māori agribusinesses are key to maximising the primary sector productivity and growth potential that exists within Māori-owned land. However, participation and retention of meaningful numbers of Māori landowners and agribusinesses (MAB) in previous extension programmes has been low. Research (Kingi 2009 a,b) has long identified challenges facing MABs that other agribusiness does not experience, particularly relating to Māori Freehold Land which has some inherent land productivity issues, due to land confiscation in colonial times, and requirements linked to Māori land law. Issues include complex governance, land administration needs, small or low productivity potential- land blocks, multiple / fragmented ownership, difficulty accessing finance and water, and more. These constraints have resulted in MABs withdrawing from past extension programmes. Landowner to landowner learning built around landowner aspirations along with collective action has the potential to inform an extension approach of relevance to Māori. Shared knowledge, networks, and scale of operations can enable the realisation of opportunities from networked primary production assets and people. A “Māori Agribusiness Extension (MABX)” programme is underway where clusters, a grouping of Māori-owned land blocks or agribusinesses willing to collaborate or collectivise towards a common goal or agreed outcomes, are formed to enable collective learning to build confidence to implement land use change and support decision making.
Methods

The MABX programme’s Whāinga (Vision Statement) is to grow the number of Māori landowners and agribusinesses to make confident, well-informed change to achieve their aspirations through their primary sector assets. The Kaupapa (protocols) that the programme follows are: the extension services are tailored to the needs of Māori landowners and agribusinesses, with achieving their aspirations sitting at the centre of any plan; that advisors working in the regions, build trust with Māori landowners and act as agents of change and learning is enabled by regular monitoring and evaluation throughout the life of each project.

The programme provides support for Māori land owners and agribusinesses to make confident and well informed decisions for sustainable land use or system changes; uses a collaborative approach, group support, knowledge sharing and primary sector expertise to build the capability and performance of participants in the primary sector and implements activities that equip farmers and growers with knowledge, tools, networks and support needed to make their businesses profitable and environmentally sustainable, in a rapidly changing regulatory environment.

The extension model utilised by MABX consists of a cluster (made up of Māori landowners and/ or agribusinesses). These clusters will have a common interest, purpose, or outcome in mind; usually land blocks are at a similar stage of development and the landowners will be looking to collaborate or collectivise.

The Ministry for Primary Industries Maori Agribusiness unit has a network of advisors situated within the regions who have close trusted relationships with Māori land trusts in their rohe (region). These regional advisors gauge the interest of land blocks to form a cluster around a particular interest. A two-phase approach is implemented, discussion group and cluster project. A discussion group is formed with the intention to work collaboratively to identify shared aspirations, sharing of resources including natural resources, people, infrastructure, and equipment etc., and potential collaborative agribusiness opportunities. At the completion of the discussion group phase a project proposal is developed by the cluster with an agreement to work together. Examples of discussion group topics that are currently being progressed include: a micro-mobile abattoir, sheep milking, regenerative farming, and high value horticultural crops. Once progressed to a project, each cluster is supported by an innovation system of actors (Figure 1). Key roles within the system are that of facilitator and project coordinator. The former must be able to utilise soft skills in drawing out the landowners to allow them to take ownership as well as an ability to access a wide network of technical expertise appropriate for the cluster needs. Many of these clusters are in remote, isolated parts of New Zealand and ensuring active participation by landowners requires much time in making contact and interacting as this may take place at multiple formal and informal settings. These tasks are best undertaken by someone from the local community and sufficient time allocated (4 days a week) particularly as the project is initiated. As part of the commitment to ensure the sustainability of the activities after the exit of the Ministry, a shadow facilitator role is put in place, filled by a local person. The shadow is mentored, on the job, by the facilitator and if required undertakes some formal training. Over the life of the project the facilitator will more and more hand over running of the cluster to the shadow.

Results

The following is an example of a cluster Whangaparāoa Māori Lands Cluster. This cluster has a focus on exploring land use options and developing capability. The total area of land in the cluster is 18,000 hectares made up of 27 land blocks. An inventory of the natural resources was undertaken by professionals including soils, topography, waterways, current vegetation, and overlayed climate data. 88% of the land use is steep hill country suitable for retiring and allowing reforestation of native trees or planting exotic plantation forestry. 12% of the land can be used for less intensive pastoral systems and 5% of the land is suitable for high value crops.
The aspirations of the landowners were identified at hui (meetings) (figure 2) and reflect diversity that includes social, cultural, economic, and environmental. The aspirations are used to in the process of assessing the suitability of potential land use.

**Figure 2: The aspirations of the landowners at Whangaparāoa**

Landowners identified 60 land uses of interest with this reduced to ten or so that were suitable for the local growing conditions including mixed cropping (e.g., kūmara, hemp, durable vegetables), truffles, avocados, hazelnuts, floriculture, and secondary compounds/bioactives from native plants. This was followed by a series of wānanga (workshops) where experts interacted with landowners to explore in depth the potential for each of the ten or so crops. The programme continues with development of a business plan and capability development plan that will be used to identify potential investors, market partners, and training programmes.

**Conclusions**

Of importance to New Zealand are the cultural values held by Māori. Cultural values shape Māori worldviews, form the basis for decision-making, and are fundamental for establishing aspirations, desires, and priorities (Marsden 1975; Marsden and Henare 1992). Traditional concepts and beliefs still resonate strongly within contemporary Māori society. Cultural values therefore reflect both the long history and relationship tangata whenua (people of the land) have with a given area, location, catchment, or region and their world view, strongly influencing land use decisions. It is critical that the aspirations form a focal point for framing the conversation and work.

Key lessons to date have been the critical role of the regional advisor and the large amount of time required to set up the discussion groups and gain agreement on participants and topic. The importance of the landowners having a right of veto of facilitator and experts to retain ownership and build trust. Embedding monitoring and evaluation throughout the life of the programme helps guide success as does building in the ability to be flexible and adapting the programme of work to retain relevance as the cluster participants become more informed and identify pathways that they wish to explore.

Key challenges now include reaching out to the landowners who do not live in the area so that they are aware of the potential opportunities; inclusion of rangatahi (young people) as the decisions made now will directly impact on them as the next generation to manage the land and linking the potential opportunities to regional development in housing, health and making the location attractive to those rangatahi who will come home to run the agribusiness.

**Acknowledgments**

Note that all Māori words are in bold followed by a translation in brackets. We acknowledge funding for this work from the New Zealand Ministry for Primary Industries. We also acknowledge all the regional advisors working in the MABX programme and the cluster participants. We particularly thank the Whangaparāoa cluster for sharing their knowledge with the global community.

**References**


MPI (2013) Growing the Productive Base of Māori Freehold Land (MPI February 2013) p4,5,7; Growing the Productive Base of Māori Freehold Land – further evidence and analysis (MPI December 2014) p20, 21


Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

Rangeland in Marajó Island, Brazilian Amazon, a Long History of Commons for Small-Breeders

Barbosa, T.,¹ Opplert, M.,¹,² Folhes, R.,³ Carvalho, S.,⁴ Tourrand, J. F.,⁵
¹Cirad; ²Universidade de Brasília-CDS; ³Museu Paraense Emílio Goeldi; ⁴Universidade Federal do Pará

Key words: Commons; Small-Breeders; Marajó Island; Policy-Making

Abstract
Rangelands cover almost one third of the earth’s surface and are characterized by a low productivity and high sociocultural value. But the lack of recognition of the environmental, social and economic values of rangelands, along with the expansion of agribusiness, tourism and urban sprawl, give rise to a rangeland dilemma. This dilemma is found in various regions of the world, where this set of factors leads to the generally irreversible destruction of the rangeland. The process is recent in the Amazon rangeland, such as the eastern part of Marajó Island and the Low Amazon wetlands. A survey conducted on 90 small breeders intended to describe, explain and model the dynamics and resilience of family and community socio-ecosystems in the rangeland area of the island of Marajó. The main result is the adaptation and resilience of small-breeders facing global change, especially the use of mobile phone and internet applied to marketing of local products. The major constraint seems to be the lack of coherent policies, both for local population livings and the maintenance of rangeland environmental services.

Introduction
Rangelands are a set of socio-ecosystems which are essential for humanity, especially in terms of water cycle, erosion reduction, biodiversity and carbon sequestration. Yet they are facing the expansion of human activity, largely agricultural, leading to the irreversible destruction of natural ecosystems for the implantation of intensive and unsustainable agricultural systems.

Collective use and landownership in rangeland area were the main rule for pastoral societies in all the continents over the past centuries and millennia, even, according to the zone, diverse local mechanisms allowed avoiding resource degradation and maintaining sustainability of socio-ecosystems. The “Tragedy of Commons” (Hardin, 1968) showed the limits of common use, especially the land degradation linked to the mutual risk and private benefit regarding the resources. Olson (1999) also demonstrates that rational individuals, guided by their own interests, will not act collectively unless given specific incentives. But some authors support the idea that the value of collective action in terms of common goods can be a valid and sufficient incentive to participate in the action (Muller and Opp, 1986).

Ostrom (1990) shows that the prescriptions of current policies are based on external intervention, or on the privatization of the common resource considered. On the one hand, an external agency would have a cost that is not taken into account, and would need access to information, monitoring capacity, and reliability in sanctions. On the other hand, privatization is impossible in many cases because the common good cannot be divided, or its division cannot be done correctly. The author argues that there are many different solutions for different cases, and that more needs to be learned from the experience of the affected individuals.

The objective of this study was thus to compare the points of view of breeders and local stakeholders regarding the collective approach of rangeland management, in order to better understand the breeders’ perceptions on their respective situation.

Materials and Methods
Study Site
The Marajo Island is located in the Pará state in Brazil, it is part of the Amazonian biome and at the mouth of the amazon river. Marajó has about four hundred thousand inhabitants located in sixteen counties, and 56% of its population lives in the rural area. The main towns are Soure, Salvaterra, Joanés, and Cachoeira do Arari. The archipelago is divided in two parts, the forest, that makes up for two thirds of the region, and
rangeland, the last third, at the eastern part of the island. Marajó Island accounts for more than 38% of the buffaloes in Brazil (Lopes Filho, 2016). The buffalo was introduced to the Marajó Island in 1895 by a Pará breeder (Marques et al., 1998). The native pastures of poorly drained savannas in the archipelago cover 2.3 million ha and are part of the 75 million ha of native pastures in the Brazilian Amazon (Lopes Filho, 2016). These areas are devoid of forest and composed of grasses and other herbaceous and palm trees (Barbosa et al., 2012). The herd made up of cattle and buffalo is raised loose in native pastures for the breeding and fattening of animals (De Oliveira et al., 2016).

Land concentration started in the eighteenth century when the island was divided into 50 sesmarias. The rangeland part was invested faster as control was easier than on the forest-covered land. It is during the Military Government period that land concentration was consolidated in Marajó, with the emergence of new landowners of both national and foreign companies (Barbosa et al., 2012). But few of the traditional inhabitants of Marajo were able to take advantage of the land ownership opportunity. The result today is a land situation made up of huge properties, which have become ranches, controlled by a few families, with diverse communities of descendants of original population on common land in the gaps. They represent 13% of the farms but use 90% of the land. Over the decades and centuries, small producers took over small plots of land that they cultivate for their subsistence. Population growth means that young people settling in must either divide up their parents’ land or lease land from the ranches. Small producers represent 87% of the farms, with only 10% of the land (IBGE, 2017).

The livestock activity started in the 16th century with just a few animals on the farms, but it is only in the 19th century that buffaloes were introduced in the island. Zebus were introduced in the twentieth century, as well as pasture improvement with cultivated fodder. The lack of pasture management leads to serious pasture degradation. In order to stop this degradation, the investments in pasture management are very high, that’s why until now the only recuperation method is to implement cultivated pastures, which destroy the natural rangeland. Family farming suffers from land access issues, common land management problems and the lack of policy. In addition to that, small producers find low public support due to the lack of land status and a weak awareness for capacity building in sustainable agriculture, food processing and social organization. It is very common to see short cycles of slash and burn agriculture, as well as the use of chemicals.

A survey by questionnaires on 90 small breeders located in five communities of Marajo rangeland area was developed in 1994, 2004 and 2019 in order to describe their farming systems and the dynamics, over the past 25 years. We established a diagnosis of production systems and agrarian systems in communities of grasslands in Marajó. This study made it possible to trace the evolutionary trajectories of these farms and communities.

Results
The main result is the adaptation and resilience of small-breeders facing global change, especially the use of mobile phone and internet applied to marketing of local products. Reduction of commons is also an important change. Additionally, it was noticed the strong demand of young people for high-level education, college and university. The producers found that the community aspect of agricultural production, livestock, as well as social life and culture, is always weakening due to the increase of individualism (fence in the areas), sales of large farms (which previously generated employment) and lack of leaders. However, some initiatives, especially in cheese production and fruit marketing (mainly Açaí) show relevant innovations (cooperatives, direct delivery to consumers, communication network, etc.). Above all, the major constraint seems to be the lack of coherent policies, both for local population livings and the maintenance of rangeland environmental services. The island lacks infrastructures in various sectors such as public health, education, access to clean water, energy, local transport, communication and the accommodation of tourists.

Two main points emerge from the analysis: on the one hand a progressive and problematic degradation of rangeland, on the other hand, the development of intensive agriculture supported by policies. Rangeland degradation is linked to a low productivity of the current land use, and has an environmental impact, especially on the biodiversity. We are witnessing a strong economic and social gap between farmers and small producers. Indeed, the development of intensive agriculture is worsening this gap and enhancing the environmental impact.

What are the future scenarios for the Marajó ecosystems? We can see three options. The first one is if no significant changes happen regarding policies, which we think will lead to more degradation of rangeland in ranching, more rural exodus especially within the youngest part of the population, and both land conflicts and local violence due to a serious social gap.
The second option is the development of intensive agriculture with investments allowed by specific policy, which could lead to economic development with local employment, but would also contribute to rangeland destruction and serious pollution risks.

The third option is an adequate rangeland public and/or private policy, which could lead in an appropriate land access for the landless and small producers, with technical and financial support to encourage rangeland management, and capacity building in sustainable agriculture and social issues.

**Discussion [Conclusions/Implications]**

We conclude on the importance of local/national and specific policy for the rangelands, waiting for the implementation of a global policy focused on this set of socio-ecosystems which are essential for the humanity, especially in terms of water cycle, erosion reduction, biodiversity and carbon sequestration. As Ostrom pointed out, national governments are often too small to govern global commons and too large to handle small-scale problems (Ostrom, 1998). As mentioned by Lemos and Agrawal (2006), we share the idea that decentralized environmental governance can be more efficient to bring local actors closer to decision making, and to promote greater participation.

**Acknowledgements**

This research was supported financially by the French Agricultural Research Centre for International Development (CIRAD).

**References**


Livestock policy in Special Areas, Alberta, Canada

Strankman, P.L.
Barbwire Communications

Key words: Sustainability; resilience; Canada; rangeland management; technological change

Abstract

Special Areas, Alberta, Canada, is a rural municipality of 2.1 million ha (about 5 million acres) in south-eastern Alberta. It is home to almost 5,000 residents, with a unique governance arrangement in Alberta. Most of the farms and ranches utilize a mix of crop and livestock primarily annual cereal and oil seed cultivation and beef cattle. These production units are usually a mosaic of privately-owned land and Crown land leased from the government. It provides an interesting case study for the local, and national challenges facing western Canadian agriculture. It also provides an opportunity to contrast with different bioclimatic and socioeconomic cases in other areas of the world. This case study will analyse the main changes in the area over the past 100 years according to the following four drivers: technical/technological changes, market and supply chains, socio-demographic trends, and public policies. These drivers include a discussion of rangeland and forage management that has increased value to the resource, including branding organic and natural and sustainable products, and development of systems for payment for ecosystem services. A variety of technical and technological changes have provided opportunities to manage for long term economic and environmental sustainability. The socio-demographic challenges and opportunities facing the area will be considered.

Introduction

It is argued Special Areas is one of the areas in Western Canada that should have never been ploughed. These lands had been inhabited for centuries by nomadic indigenous peoples who followed the buffalo. Initial exploration in late 1850’s found a barren prairie in the drought portion of the weather cycle that continues to mould and challenge inhabitants today. Reports warned much of the land would never support human life. However, years later, ranchers drove herds of longhorn cattle up from Texas finding ample grass, and good water supplies (Gorman, 1988).

Public policy has played a key role in the history of Special Areas. The settlement of the first pioneers was the result of the Canadian government’s policy at be beginning of the 20th century, to occupy the western territories by building a railroad to cross the country from east to west. Before the settlers arrived the dominant land-use was indigenous peoples living a gathering and hunting life based on bison grazing natural grassland.

Successive policies since the mid-19th century in Alberta’s rangelands have had a major role in the settlement of immigrants and in their permanence on their lands, and in the construction of a rural society based on livestock farming. The focus area is south of the North Saskatchewan River, and running to the northern border of the United States covering most of the southeast corner of the province.

By the late 1920 there were 26,000 people living in the area presently known as the Special Areas. This was much more than the rangeland transformed into cultivated land could sustain. Recurring droughts hit the region with sandstorms causing terrible soil erosion due to rangeland degradation. The depression years of the 1930’s, especially the strong falling prices, led to disaster and hardship in Special Areas. Farmers defaulted on loans and taxes, 27 rural municipalities were bankrupt and over 2.2 million acres (900.000 ha)
of land was lost under tax recovery proceedings. The economy collapsed.

After an economic depression and drought in the 1930s decimated the area, the Alberta Government established a special governing body to provide municipal services. Administered under the authority of the Special Areas Act, the Minister of Alberta Municipal Affairs, through ministerial order, delegates authority to the Special Areas Board to provide those services. This Board is responsible for the administration of about 2.6 million acres of provincial Crown land. The land is leased directly to agricultural producers for grazing and cultivation by the Special Areas Board. The majority of the farms and ranches in the area produce a mix of annual cereal and oil seed crops, and almost exclusively beef cattle with a few producers raising sheep.

Drivers influencing land use change in rangelands and grasslands of the world can be grouped into four areas: i) technical changes, ii) market and supply chains, iii) socio-demographic trends and iv) public policies. This paper discusses how those drivers have impacted change in Special Areas, Alberta, Canada.

Discussion

Technical Changes

Technological advances meeting the demands of climate and markets have long been the source of prosperity in Canadian agriculture. The word technology suggests the high-tech world of grain production or hog barns. However, cattle producers tend to think more of management tools, e.g., managed grazing using electric fences; limit access to wetlands to decrease diseases like foot rot and improve animal performance with improved water quality. Another tool is adding legumes to a seeded grass mix primarily to increase productivity but with collateral benefits such as decreasing methane production from cattle digestion.

A recent study of leading-edge cattle producers in Alberta found active participation in regional forage associations, or applied research organizations, attending field tours and seminars was an important characteristic. It is long recognized that management practices must be customized to each farm. Exposure to new ideas and innovative thinkers is an important factor in making changes efficiently. Producers see the cattle and their relationship with the land as being complex. They see a need for systems thinking but also emphasize their needs to be a balance, utilizing technology and keeping management simple (Strankman and Reid, 2013).

Market and Supply Chains

The last decade has brought significant challenges for the Alberta cattle sector. Drought in 2002 forced many to bring down cattle numbers because the pasture grass to support them was not there. That type of unplanned marketing causes expensive disruption in breeding and marketing programs and has tax implications. Then in May 2003 the industry was rocked by the discovery of bovine spongiform encephalopathy (BSE) which closed the border to exports. Canada is still dealing with residual trade restrictions. Through the last half of 2007, the rising Canadian dollar and high feed costs created significant additional financial hardship for cattle producers. This was followed by the global economic crisis of 2008 that further eroded sale prices for cow/calf producers. In addition, in late 2008 the United States implemented Country of Origin Labelling (COOL) causing a significant negative impact on Canadian beef export prices. With about 50% of Canadian beef production going to the US, Canadian prices are essentially set by the net price received from shipping to the US. COOL discrimination costs Canadian cattle participants around $640 million per year. This presents a dilemma given that about 85% of Canadian beef and cattle export trade is with the US generating 1.8 billion CA$ in total sales (Canadian Agri-Food Policy Institute, 2012).

Special Areas cow numbers have followed the Canadian trend, decreasing since 2005. Canada’s cow herd has decreased by one million head (20%) since 2005. How Canada will ensure sufficient cattle supply to meet the future market opportunities is challenging. Per capita consumption of beef is falling domestically (10.7% since 2001) and across the Organisation for Economic Cooperation and Development (OECD). This is contrary to the increase in meat consumption in the developing world. The predictions for continued growth are based on the increasing affluence of middle classes. Canada will need to find ways to effectively out compete other beef exporting countries which are also developing marketing strategies to serve these markets.

Nearly 60% of Canada’s beef is produced in Alberta. The largest confined cattle feeding network and the largest beef processors are located there, and beef is Alberta’s number one agricultural commodity.
Most Special Areas cattle producers market their 500–600 lb (227–272 kg) pound calves in October/November. Generally, the calves will go directly into confined feeding operations to be fed to a finished weight of about 1200 lbs (544 kg). Some calves may go to what is termed backgrounding operations to be fed primarily forages for some time until market conditions determine timing is good to begin to bring them to market weight. Canada markets a grain finished beef, so the calves are fed increasing amounts of grain until they reach their finished weight. That grain is generally barley unless corn prices in the US make it economically advantageous to import and displace the barley in the ration.

Some of the challenges to managing Canadian beef marketing are as follows: reducing dependency on the US market; leveraging strengths of animal identification and traceability in select markets; creating traceability through entire beef chain; growth of domestic market based on an increased understanding of consumer needs; improving communication on consumer issues such as nutrition and product preparation; effectively utilizing the Canada brand through the Canadian Beef Advantage program (Canada Agri-Food Policy Institute, 2012).

**Sociodemographic**

In 2011 there were 847 farms and ranches in Special Areas with 475 reporting having cattle (Statistics Canada, 2011). This was down 122 farms from 2006. Number of cattle in the area had dropped by about 43,500 heads from 2006 to 2011. The land in Special Areas is about 45% privately owned with the other 55% leased from the Special Areas Board (Government of Alberta 2009).

In the recent past, a portion of farms in Special Areas are able to supplement their income with revenues linked to oil or gas-well drilling, or natural gas pumping station. Land access payment for the drilling of a gas or oil well was in the neighbourhood of 1,400 CA$ a year. The Alberta strong oil-based economy pushed many young people to migrate for wage employment in urban areas, i.e., close to services and with more flexible working hours. However, recently the decline in the oil industry has had a serious impact on the provincial economy and the access payments to landowners.

Decreasing agricultural income raises questions regarding the farm/ranch viability for the next generation. Declining farm incomes also have a negative impact on intergenerational transfer within the agricultural community with young potential farmers being driven to urban areas for employment and resulting depopulation of the rural area (Canada, Parliament, Senate, Standing Committee on Agriculture and Forestry, 2006).

Although there are numerous and significant economic and social challenges in this region, there is also a strong sense of community and a spirit of cooperation. Most of the residents do see the area as special, with a natural beauty in the native grass lands and its wildlife. There is uniqueness to the region believed to be marketable. However, to date only traditional recreation opportunities in the form of parks, campgrounds and golf courses have been developed.

**Public Policy**

As discussed earlier the federal government policy in the late 1800s encouraged the cultivation of the native grasslands. However, it is now Special Areas policy and regulation that encourages the retention of rangelands.

Land use management in Special Areas is influenced by a mosaic of federal, provincial, and municipal division of power and responsibility in the areas of agriculture and environment. Environment is one policy area where there has been growth in intergovernmental administrative interactions responding to the increase in bilateral and multilateral intergovernmental agreements. Agriculture and Agri-Food Canada, on the other hand, has managed intergovernmental relations by integrating into several department units. All provincial governments have adopted the concept of sustainable development or sustainable resource management and this influences municipalities such as Special Areas (Kennedy and Donehee, 2006).

Increasing producers’ profitability has long been the primary goal of Canada’s federal and provincial agriculture departments. Farm incomes have been supported and stabilized by a variety of policy instruments with market promotion and trade liberalization being the favorite for the export-oriented grains, oilseeds, and livestock sectors (Skogstad, 2011).
Perhaps the most significant recent change in Canadian agriculture policy was how the federal and provincial governments interacted on the development of what was called the Agriculture Policy Framework (APF) (2003–2008). For income safety nets/business risk management programming, there was a five-year government commitment of funding as opposed to the former three-year agreements. Secondly, business risk management goals were clearly linked to public goods such as food safety and environmental protection (Skogstad, 2011). APF was identified as being an integrative approach to agriculture policy support, agricultural economic viability and improving environmental performance and benefits to society. Subsequent frameworks, Growing Forward I and II, weakened that integration (Strankman, 2014).

Through APF 2003–2008, an important agriculture sustainability tool was developed and delivered in all provinces: a Environmental Farm Plan (EFP). This process supported producers identifying risk and developing a plan to reduce those risks. A suite of 30 Beneficial Management Practices (BMP) received federal and provincial funding. The majority of the BMPs increased agricultural productivity by increasing efficiency, however, there were several BMPs, such as Riparian Area Management, Shelter Belt Establishment, Invasive Alien Plant Species Control, Species at Risk, Grazing Management Planning, Biodiversity Enhancement Planning, positively impacting livestock production (Agriculture and Agri-Food Canada, 2006).

In Alberta, the Alberta Land Stewardship Act (ALSA) was passed in 2011 to support a transparent and accountable regional planning process (Alberta Government 20). These regional plans will integrate provincial policies, setting regional land-use objectives, providing context for land-use decision-making within the region, and reflecting the uniqueness and priorities of each region. Special Areas will be involved in the development of the Red Deer regional plan which supports a sustainable development approach by integrating economic, environmental, and social factors, and ensures that planning for land use, water and air quality are aligned.

These plans will develop a strategy for conservation and stewardship on private and public lands promoting efficient use of land to reduce the footprint of human activities on Alberta’s landscape. These plans if delivered with the promised support and monitoring system should contribute to continuous improvement of land-use planning and decision-making to the benefit of livestock producers in Special Areas.

The livestock producers in Special Areas and the rangelands of Alberta and Canadian Prairies continue to overcome challenges brought by weather and markets. The communities are strong, and the people determined. The spirit of rural people finds opportunities in markets, technology and the traditional ways and stewardship of the land continues.

References

Canada, Parliament, Senate, Standing Committee on Agriculture and Forestry, 2006. Agriculture and Agri-Food Policy in Canada: Putting Farmers First!


Strankman P., Reid J., 2013 Strategic management approaches used by leading edge cow/calf operations in Alberta. Prepared for Agriculture and Agri-Food Canada.
Intensive Poultry Production as a “Collective” Initiative to Face Global Change in the Bedouin Area of the North Western Coast Zone (NWCZ), Egypt

Daoud, I., Osman, M.A., Alary, V., Tourrand, J.F.

1 Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Damascus, Syria
2 Agricultural Research Center (ARC), Animal Production Research Institute (APRI), Cairo, Egypt
3 Agricultural Research for Development (CIRAD), Montpellier, France
4 Agricultural Research for Development (CIRAD), Montpellier France / UFSM, Santa-Maria-RS, Brazil

Key words: Diversification in animal production; Socio-cultural issue; Sustainable alternatives for livestock farming system; Bedouin society;

Abstract
The North West Coast Zone (NWCZ) suffered a severe and long drought from the middle of the 90s to 2010 with an annual average rainfall less than 140 mm. Consequently, the rangeland pastoral resource progressively disappeared; above all the process was exacerbated by overgrazing. Moreover, the social situation was complex linked to diverse land conflicts between the Bedouin tribes and the successive military governments for the control of subsoil resources, especially oil and gas. Due to the lack of natural forage, small ruminant feed in the NWCZ became mainly based on by-products and cultivated forages produced in the Nile Delta and Valley, above all clover (Trifolium alexandrium). In order to buy feed and limit their production costs, many breeders reduced their flock size, keeping preferentially the main productive animals, young females for reproduction and male lambs to be fattened and sold for religious slaughtering. Facing the reduction of small ruminant productivity, the local Bedouin society imagined and developed some initiatives, including an intensive poultry production as an attractive alternative, especially for young breeders and consequently to avoid their migrations to the Gulf countries. Intensive poultry production is frequent in the Nile Delta and Valley. In the same way as in these regions, intensive poultry production in the NWCZ is based on the exportation of final products (broilers, turkeys, etc.) to Europe markets. So, local Bedouin society of NWCZ, including diaspora, financed training and infrastructures in order to secure this new initiative, as for example feed factory for poultry nutrition, providers of specific equipment for poultry barns, consulting agencies offering training and support, etc. The collective effort of local Bedouin society was not officially planed, but clearly appears defined and shared among the diverse leaders.

Introduction
In a research study case on Bedouin livelihoods in the North Western Coastal Zone of Egypt (NWCZ, see map below) conducted between 2010 and 2015, the adaptation processes to global change, especially climate change, were analysed mainly due to a long drought from the middle of the 90s to the end of 21st century first decade with less than 150 mm annual rainfall (Alary et al., 2014). The NWCZ extends 450 km from Burj Al Arab to El Saloum on the Libyan border. Bedouins arrived in the area in the 11th Century. They are organized in tribes which are the pilar for social issues, especially land access. The map below (Daoud, 2015) shows the land distribution among the tribes. In the past, Bedouin breeders lived in tents. Nowadays living is in sedentary communities (Picture).
Traditional Bedouin socio-ecosystem is based on breeding on natural rangeland pastured by herds of small ruminants and camels. Rainfed barley is cultivated for human consumption and is pastured by herds when the pluviometry is not sufficient for grain production (Daoud, 2015). The strong herd productivity decreasing due to the lack of natural forage during the 15-year’s drought led breeders to invested in diverse additional income alternatives to firstly provide by-products to feed their herds, and secondly maintain their livelihoods. In this paper, we explore the intensive poultry production which appeared as an incredible alternative due to the huge difference with the extensive Bedouin livestock system.

Methods and Study Site

Regarding the specific research on intensive poultry production, informal interviews were applied with producers and local stakeholders in order to collect information on the different topics including (i) origin of the initiative in the farms, (ii) objectives of the intensive poultry production, (iii) training of workers and technical support, (iv) providing of specific equipment and materials, especially for nutrition and disease control, (v) marketing of the production, (vi) financial aspects and (vii) evaluation at farm and local level.

This specific research on intensive poultry production took place in a larger research developed in the ElVulMed project financed by French Agency for Research (ANR). The ElVulMed team conducted the research along a west-east transect from Sidi Barani (located approximately 100 km from the Libyan border) to Burg Al Arab (located 60 km from Alexandria). The study area comprises six districts distributed in 4 zones. From 30 to 50 families was surveyed in each zone; the families were selected along a north-south gradient from the coast to the desert area according to the amount of livestock they owned. All the interviews were conducted in situ. In this study, a ‘family’ unit includes one or several households that are mutually dependent for livestock and land assets and cash income. Each household is a standard nuclear family (husband, wife and their children).

Two main research tools were used in the ElVulMed project to gather data for this study: interviews with local leaders and key informants and structured interviews with individual families. Interviews with key informants were informal and were designed to gather qualitative data on Bedouin society as a whole, its organization, and relations with Egyptian society as a whole and with administrative institutions, their perception of social and economic changes in the study area and beyond, and finally, the place and role of livestock in recent decades. The interviews with the families were based on a structured questionnaire. and the interviewee’s general perception of changes in climate, productivity, social relations. Survey data from 182 families were broken down into seven themes.

To determine the changes and development of the poultry farms establishment in wadi Naghmish area as an example for the North West Coat Zone of Egypt, ARCGIS 1.6 was used to show those changes in the period from 2007 until 2020.

Results

**Significant change in small ruminant herd management due to the 15-years drought**

For Bedouin breeders and local stakeholders of the NWCZ, in a year with regular rainfall, the small ruminant herds need supplementation around three months, from July to October.
Natural pasture and barley crop residues are sufficient for the other nine months. Moreover, the traditional small ruminant management was adapted to the local climate, especially it allowed the livestock keepers to deal with the effects of a three or four-year’s drought. During these dry years, rangeland natural forage and barley crop residues are insufficient to sustain the herds for at least eight or seven months (Daoud et al., 2020). Consequently, the breeders sold more animals in order to purchase feed for their herds and food for human consumption. The herd size decreased, but it increased again when sufficient rainfall was received in subsequent periods.

According to the same breeders and local stakeholders, from the beginning of the 15-year’s drought in the middle of the 90s, the livestock conditions changed. Nowadays, the natural pasture sustains the herds just three or four months and barley residues are weak due to low rainfall. Breeders have to feed their herds with by-products around eight or nine months a year. Even if the rainfall is good, the rangeland productivity is low due to land degradation caused by 15-years overgrazing with disappearance of several plants, especially herbaceous, and loss of fertile soil due to wind erosion (Daoud et al., 2020).

Breeders have adapted their herd management to the new conditions, mainly reducing the herd size and using more purchased fodders per animal. Some policies helped us to face this change, but they are not sufficient. A few interviews are registered in a short movie available (https://youtu.be/zbRgCKmm6YI). To face the decreasing of their income and to maintain their life conditions, breeders invested in other activities. A few of them, those who accessed to wadi lowlands, have developed perennial and annual cultivation supported by specific projects (Alary et al., 2012). The others had to find alternatives.

Diverse alternatives for additional income in order to maintain their livelihoods.

One of the more frequent alternatives chosen for Bedouin breeders is investing in animal and fodder trading (pictures below), profiting their recognized skill in animal production. Others are becoming workers in Marsa Matrouh city, especially in local transport and building construction, two dynamic sectors due to tourism expansion. For these options, Bedouin breeders need support of their networks, especially inside their respective tribes. Exist some other alternatives linked to tourism expansion in Marsa Matrouh city, as for example open a shop or a workshop profiting opportunities (Pictures).

Migration to find a job is also an opportunity for many breeders, especially young people. The migration is to big urban centres, as Cairo and Alexandria, or in the Gulf countries, or eventually in Libya to be shepherd. However, the migration needs efficient support of his tribe to be informed about job opportunities, to be recommended, to organize the travel and find local support at the arrival, etc. At least, there was the investment in an intensive poultry production.

The intensive poultry production in the NWCZ

According to Alary et al., (2014) the Bedouin breeder who invested in poultry production were usually middle-aged married men who did not want to migrate. He has not opportunity or capital to invest in another alternative. His decision came progressively seeing some neighbours or parents. Once convinced, he contacted a poultry trader to start his own poultry unit.

The poultry trader provides 2-day-old chicks, different kinds of feedstuff depending on the age of the broilers. The trader is in charge of marketing, technical support and is the guarantor for all the suppliers. The farmer only has to pay for the chicks and feed when he sells the broilers, at the end of each batch. Based on mutual confidence, the trader knows the farmer who belongs to his own tribe (Alary et al., 2014).

The new poultry farmer has to invest in a simple 600 m² barn built from cinder blocks and bricks, with windows for ventilation, and equipment based on the model used in the NWCZ. Financing the first barn is the main obstacle to start, around US$10,800 in 2012. Usually, the new poultry farmer sold his flock; invested his savings and, if
necessary, borrowed the rest from his family and his tribe (Alary et al., 2014).

At the beginning, each 5,000-broilers barn requires two workers, the farmer and one from his family. One or both need to have already worked on a poultry farm to know the basic rules of poultry production, including feeding, checking the lighting, ventilation and watering, diagnose the first disease symptoms. Later, the workers’ number depends on the barns’ number, three workers for two barns, four workers for three barns.

Table 1: Technical-economical Parameters from a 5000-broiler production unit (US) (Alary et al., 2014)

<table>
<thead>
<tr>
<th></th>
<th>Cost of 5000-day-old chicks</th>
<th>Margin on chicks and feed</th>
<th>Cost of feed for one batch</th>
<th>Margin on total costs</th>
<th>Other costs</th>
<th>Building/batch of broilers</th>
<th>Manpower</th>
<th>Total costs</th>
<th>Total products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of 5000-day-old chicks</td>
<td>2 100</td>
<td>2 450</td>
<td>12 600</td>
<td>1 300</td>
<td>250</td>
<td>550</td>
<td>350</td>
<td>15 850</td>
<td>18 300</td>
</tr>
</tbody>
</table>

Four main factors explain the success of poultry production in terms of performance: the national market, which absorbs all the broilers; the Bedouin ‘quest’ for efficient farming systems to survive drought; the absence of poultry diseases in the region; and, finally, the capacity of the tribe to organize the poultry chain—mainly based on trust and personal guarantees provided by the tribe— and access to the national market. Other contributed factors were space availability for barns, local laborers’ ability to learn rapidly, three poultry feedstuff factories and poultry production experts in Marsa Matrouh (Alary et al., 2014).

In the future, certain factors could prevent its continued expansion, as diseases will certainly appear over time and depending on the number of buildings, as well as on the quantity and quality of water available.

Discussion [Conclusions/Implications]

The social structure of the Bedouin community has special nature. Tribe is the most common social unit. The existence of the border between the tribes affects the freedom of movement among the herds but at the same time prevents a lot of social problems as a result of grazing (Daoud, 2015).

As a result of the long drought in the North West Coast of Egypt in the period from 1995 until 2011, the Bedouin community showed an important flexibility to adapt to drought conditions through various strategies to reduce the vulnerability to drought. Poultry was one of the late strategies which appeared widely in the area. It appeared that this activity started in the region in 2007. Then many breeders noticed the high income generated from this activity; some of them decide to sell their flocks to establish new poultry farms in the area. The expansion was very rapid. Selling of flocks was not the only source of funding; the other sources were the income-return from working in Libya or collaboration of the farmers with another person’s in the city who had the capability to fund this activity. The risk is high in this activity, but in case of success the income is very high. In one cycle, which is about 40 days, the farmer can get from 15000 to 20000 Egyptian Pound, but maybe he will lose the amount or more in bad conditions. Many reasons make the risk very high in the poultry sector, such as the unexpected change of the feeding price for both feeding cost and poultry prices. The farmer cannot control this change.

It can be said that diseases, bad weather and price fluctuations in the market are the most important causes of risks in the field of poultry farming in the region, and despite the success of this activity in most cases in achieving a quick and high return, its risks are very severe for the breeder as the risks are sudden and unpredictable.

It is also noticeable that collective action, which is one of the most important means of reducing risks, is completely absent in the region, where despite the wide spread of these farms, there is no entity or association that can bring these breeders together.

In addition to the aforementioned risks, the failure to formally establish these farms makes them subject to the efforts of the breeders based on their previous experiences or a tradition of neighbors who preceded them in establishing these farms, as it can be seen that most of these farms were established in a very traditional and simple way.

At the present time, some private companies have appeared in establishing more advanced
farms based on sound scientific foundations, and therefore the productivity is better and the risks are less compared to the simple traditional farms common in the region. The high cost of these modern farms is still a hindrance for a simple breeder.

Acknowledgements
To ElVulMed Project (https://elvulmed.cirad.fr/en) and MOUVE Project (www1.clermont.inra.fr/mouve/) both financed by the French National Research Agency (ANR).

References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forage and Animal Nutrition
Nutritional Characteristics of Different Grass and Legume Mixtures Estimated in In Sacco and In Vitro Gas Production

Yvette Giramahoro, Callixte Karege, Horacio Gonda and Mupenzi Mutimura

1Department of Animal Production, School of Veterinary Medicine, University of Rwanda, PO Box 4285.
2Swedish University of Agricultural Sciences (SLU), Box 7024; 750 07 Uppsala, Sweden.
Rwanda Agriculture and Animal Resources Development Board (RAB), P.O. Box 5016, Kigali, Rwanda

Key words: Rumen degradation; mixed grass-legume diets

Abstract
A study was to compare rumen degradation characteristics of different grass and legume mixtures estimated in sacco and Menke gas production techniques. Five forages including Chloris gayana as control and four (4) mixtures of C. gayana and Cratyli a argentea; C. gayana and Canavalia brasiliensis, C. gayana and Desmanthus virgatus, and C. gayana and Desmodium distortum were used. The mixture was 70% of grass (Chloris gayana) and 30% of each one of the legumes. In vitro gas production and in sacco technique were used to estimate organic matter digestibility (OMD), metabolisable energy (ME), kinetics coefficients and dry matter disappearance (DMD). Feed samples were incubated for 72 hours for both techniques. Data on gas production and DMD were recorded for in vitro gas production and in sacco techniques, respectively. Results showed that gas production, kinetics coefficients, OMD and ME were higher when C. gayana mixed with forage legumes compared to the grass alone. In sacco DMD was higher when C. gayana was mixed with legumes. For both techniques, C. gayana mixed with Desmodium and Canavalia improved the grass’s nutritional characteristics, including DMD, OMD and ME. The two techniques were also correlated and thus using one of the methods is enough for better feed evaluation. Results confirm that the inclusion of legumes to a low quality grass based ration can improve the nutrient supply. Therefore, based on their higher nutritive value, legumes may be recommended as a cheap source of nutrients to supplement Chloris gayana diets in ruminant livestock.

Introduction
In tropical countries, livestock productivity is greatly limited by poor nutrition due to feeding high fibre feed commonly deficient in nutrients like nitrogen, sulphur, phosphorus, and other minerals essential for a sustainable ruminal microbial fermentation. Indeed, available feed to cover the animal’s requirements in Rwanda, are forage legumes and grasses, crop residues, and commercial concentrates. Fodder growth, utilization, quantity and the quality depend on the season resulting in a poor production (Minagri 2013). During the dry season, the quantity of fodder is inadequate and its quality is poor, and only few farmers can afford to feed commercial feeds. One way to improve the performance of ruminants is through better feeding to improve nutrient uptake on offer (McGrath et al., 2018). In Rwanda, however, farmers experience the shortage of forages and have less understanding of the nutritional characteristics of available feed resources. This makes feeding practices difficult and thus, unpredictable animal performance. Notwithstanding this, better knowledge of the nutritive values of available feed resources would help in ration formulation and prediction of ruminant performance. The objective of the study was to characterize and compare rumen degradation characteristics of different grass nutritionally and legume mixtures estimated by in sacco and Menke gas production techniques.

Materials and Methods
Study location
The study was conducted at the animal nutrition laboratory of Rwanda Agriculture and Animal Resources Development Board (RAB). The station is located at 2º 29’ S and 29º 47’E at an altitude of 1,630 m a.s.l. This location has two major seasons; dry season (June, July and August) and rainy season (March, April and May). Rainfall varies between 900 and 1,400 mm per annum (Nishimwe 2007).
Forage

Four legume species namely *Cratylia argentea*, *Canavalia brasiliensis*, *Desmanthus virgatus* and *Desmodium distortum* were collected from former Karama station of RAB located in Eastern Province, Bugesera district. The area is characterized as semi-arid with 4 to 5 months of the dry season. Karama station is located at 30°25’E and 2° 30’ S at an altitude of 1,250 m a.s.l. The area gets an average annual rainfall of 750 mm with an average annual temperature of 21°C (Gilber 2015). The other forage used was one grass species (*Chloris gayana*) collected at Rubona RAB station.

Animal

A fistulated cross-bred steer (Frisian x Ankole) of live weight of 452 kg was used to get rumen fluid for *in vitro* gas production and *in sacco* degradation experiments. The steer was fed with *Chloris gayana* hay, supplemented with salt and de-wormed for at least 21 days before collecting rumen fluid and *in sacco* incubation. Water was provided *ad libitum*.

Mixture grass and legume samples

Treatments (T) were *Chloris gayana* alone (100%) and a mixed of *Chloris gayana* (70%) and each legume (30%). *Chloris gayana* alone used as a control (T1), mixture of *C. gayana* and *Cratylia argentea* (T2); *C. gayana* and *Canavalia brasiliensis* (T3), *C. gayana* and *Desmanthus virgatus* (T4), and *C. gayana* and *Desmodium distortum* (T5). Samples of dry forages were ground to pass through 1 mm sieves. The mixtures were used either *in vitro* gas production (0.2 g/replicate) or *in sacco* (3 g/replicate) techniques. The samples were incubated for 72 hours both for the *in vitro* gas production and *in sacco* in three replicates for each treatment.

Chemical composition of forages used

The chemical composition of forage species before making mixtures were determined (Table 1). Forages were harvested by hand at the flowering stage and a sample of 500 g of fresh biomass was taken and divided into two parts. One part was oven dried at C for 48 hours and kept for subsequent analysis while the other part was oven dried at 105°C to calculate the dry matter content and ignited for overnight at C in muffle to get ash, calcium and phosphorus. The dried samples at 60°C were milled to pass through a 1 mm sieve and analysed for Crude protein, crude fibre, NDF and ADF (AOAC 1995; Van Soest et al., 1991).

Table 1. Chemical composition (%) of all five forages

<table>
<thead>
<tr>
<th>Parameters</th>
<th>C. argentea</th>
<th>D. distortum</th>
<th>D. virgatus</th>
<th>C. brasiliensis</th>
<th>C. gayana</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>98.5</td>
<td>98.3</td>
<td>98.7</td>
<td>98.4</td>
<td>98.3</td>
</tr>
<tr>
<td>OM</td>
<td>88.7</td>
<td>91.7</td>
<td>91.8</td>
<td>88.1</td>
<td>91.7</td>
</tr>
<tr>
<td>CP</td>
<td>24.4</td>
<td>22.6</td>
<td>24.4</td>
<td>25.9</td>
<td>7.9</td>
</tr>
<tr>
<td>NDF</td>
<td>61.8</td>
<td>47.2</td>
<td>45.7</td>
<td>42.6</td>
<td>80.9</td>
</tr>
<tr>
<td>ADF</td>
<td>49.3</td>
<td>34.0</td>
<td>33.5</td>
<td>36.2</td>
<td>45.1</td>
</tr>
<tr>
<td>CF</td>
<td>28.3</td>
<td>23.4</td>
<td>19.2</td>
<td>26.9</td>
<td>40.0</td>
</tr>
<tr>
<td>Ash</td>
<td>11.3</td>
<td>8.3</td>
<td>8.2</td>
<td>11.9</td>
<td>8.3</td>
</tr>
<tr>
<td>P</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Ca</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td>1.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

DM=dry matter, NDF=neutral detergent fibre, ADF=acid detergent fibre, CP=crude protein, CF=crude fibre.

In vitro gas production

*In vitro* gas production was determined according to Menke et al., (1979). Volume gas production was recorded during a total period of 72 h. Cumulative gas production and *in sacco* data were fitted in the model of Schofield et al., (1994; Equation 1).

\[
Y = \frac{G}{1 + e^{(2+4c(t - t_l))}}
\]

Equation 1.

\(Y\): Total gas volume at time \(t\); \(G\): Maximum gas volume at \(t=\infty\); \(c\): Degradation rate (h\(^{-1}\)); \(t_l\): Bacteria colonisation or lag time.

From gas production, organic matter digestibility (OMD) and metabolisable energy (ME) were calculated according to Menke et al., (1979; Eq. 2 and 3).
\[ OMD(\text{g/kgDM}) = 148.8 + 8.9 \cdot G_2 + 4.5 \cdot CP + 0.651 \cdot X_\alpha \]

Where \( G_2 \) is the gas volume at 24 h after inoculation while \( X_\alpha \) is the ash content (% DM).

\[ M(\text{M/kgDM}) = 2.2 + 0.136 \cdot G_2 \cdot 0.057 \cdot CP + 0.0029 \cdot CP^2 \]

Where \( CP: \) crude protein content (%DM)

In sacco digestibility

In sacco dry matter disappearance was carried out according to the procedure described by Mehrez and Ørskov (1977). Samples were incubated in the rumen of a crossbred (Friesian X Ankole) fistulated steer of 452 kg live weight for 6, 12, 24, 48 and 72 h. The steer was fed on \textit{Chloris gayana} and, water and licking block were offered \textit{ad libitum} for 14 days before and during the incubation period. Three grams of each feed sample were weighed and placed into nylon bag in three replicates. Samples were placed into rumen starting by time 72, then 48, 24, 12, 6, and all removed at time 0. Once removed from the rumen, nylon bags were thoroughly washed with cold running water until the water became clean. Then, bags were dried at 105°C in the oven, before estimating the final weight. The dry matter losses for each mixture were determined for each time (Equation 4).

\[ \text{Disappearance} = \frac{(SW_a - W) \cdot XD_a - (SW_b - W) \cdot XD_b}{(SW_a - W) \cdot XD_a} \]

Where: \( SW_a = \) Weight of the sample + nylon bag 
\( BW = \) Weight of empty nylon bag 
\( SW_b = \) Weight of the sample + nylon bag after incubation 
\( DMA = \) Dry matter of feed sample 
\( DMB = \) Dry matter of residue sample 

Statistical analysis

The data from \textit{in vitro} gas techniques were subjected to the general linear model (GLM) procedure of SAS (2018) for analysis of variance, while kinetic parameters from DM disappearance from the nylon bag were estimated by using “solver” in Excel. Least significant difference (LSD) with significance level of 5% was used for mean comparison.

Results

Results of gas production (GP) from all feeds were significantly different \((P < 0.05)\) for the amount of gas produced (Table 2). Mixture of \textit{Chloris} and \textit{Desmodium} were the highest in GP and the smallest amount of gas was observed in the mixture of \textit{Cratylia} and \textit{Chloris}. All feeds were significantly different \((P < 0.05)\) for their rate of degradation. The highest rate of degradation corresponded to the mixture of \textit{Chloris} and \textit{Desmodium} while the lowest was in the mixture of \textit{Chloris} and \textit{Desmanthus}. All feeds were significantly different \((P < 0.05)\) for their potential degradability (PD). High PD was observed in the mixture of \textit{Chloris} and \textit{Desmodium}, while the lowest was in the mixture of \textit{Chloris} and \textit{Desmanthus}. Furthermore, there were significant difference \((P < 0.05)\) in OMD, and in their correspondent ME (Table 2). \textit{Chloris gayana} had the lowest OMD and ME, however, its mixture with \textit{Canavalia} and \textit{Desmodium} had the highest (Table 2).

Table 2: In vitro gas production and degradation parameters of grass and grass-legume mixture incubated with rumen fluid

<table>
<thead>
<tr>
<th>Feeds</th>
<th>GP (ml/200 mg DM)</th>
<th>c (h⁻¹)</th>
<th>t₀ (h)</th>
<th>a (ml)</th>
<th>b (ml)</th>
<th>a + b (ml)</th>
<th>OMD (g/kg DM)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{Chloris gayana}</td>
<td>32.84⁻</td>
<td>0.023⁻</td>
<td>40.85</td>
<td>2.55</td>
<td>30.29⁻</td>
<td>32.84⁻</td>
<td>262.4⁻</td>
<td>3.95⁻</td>
</tr>
<tr>
<td>\textit{Chloris}*\textit{Canavaria}</td>
<td>36.10⁻</td>
<td>0.023⁻</td>
<td>35.72</td>
<td>1.43</td>
<td>34.25⁻</td>
<td>36.09⁻</td>
<td>381.1⁻</td>
<td>7.27⁻</td>
</tr>
<tr>
<td>\textit{Chloris}*\textit{Cratilia}</td>
<td>34.28⁻</td>
<td>0.022⁻</td>
<td>37.97</td>
<td>0.91</td>
<td>34.80⁻</td>
<td>35.72⁻</td>
<td>338.3⁻</td>
<td>5.97⁻</td>
</tr>
<tr>
<td>\textit{Chloris}*\textit{Desmanthus}</td>
<td>34.79⁻</td>
<td>0.020⁻</td>
<td>34.24</td>
<td>7.61</td>
<td>37.18⁻</td>
<td>34.79⁻</td>
<td>333.0⁻</td>
<td>6.38⁻</td>
</tr>
<tr>
<td>\textit{Chloris}*\textit{Desmodium}</td>
<td>38.20⁺</td>
<td>0.023⁺</td>
<td>34.94</td>
<td>4.33</td>
<td>33.86⁺</td>
<td>38.20⁺</td>
<td>373.3⁺</td>
<td>6.76⁺</td>
</tr>
</tbody>
</table>

a, b, c, d, e: mean values with different superscript in a column are significantly different \((P < 0.05)\). OMD: Organic matter digestibility; ME: Metabolisable energy.
The dry matter disappearance and degradation parameters from the nylon bag technique showed significant difference (*P* < 0.05; Table 3). The lowest value was for *C. gayana* alone. With 30% inclusion of legumes in the mixtures, the degradatibility increased in all diets (Table 3).

Table 3: DM degradability (%) of Chloris gayana and its mixtures with legumes estimated by the in situ technique

<table>
<thead>
<tr>
<th>Diet</th>
<th>Incubation time</th>
<th>Degradability parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Chloris*Cratilia</td>
<td>7.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.3</td>
</tr>
<tr>
<td>Chloris*Desmodium</td>
<td>9.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.9</td>
</tr>
<tr>
<td>Chloris*Desmanthus</td>
<td>8.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.5</td>
</tr>
<tr>
<td>Chloris*Canavalia</td>
<td>9.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.2</td>
</tr>
<tr>
<td>Chloris gayana</td>
<td>1.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.1</td>
</tr>
</tbody>
</table>

a, b, c, d : mean values with different superscripts in a row are significantly different (*P*<0.05)

Fermentation kinetics using Menke gas production and in situ /nylon bag techniques

The comparison of the degradation curves calculated by the two methods used to analyse each feed showed that the shapes of the curves are similar without any clear difference with regard to over- or under-estimation method-related effect (Figure 1). Besides that, *in sacco* technique appeared to give much higher values for rumen degradation than the *in vitro* gas production technique for all the treatments.

Figure 1: Comparison of kinetics fermentation estimated by the *in sacco* and *in vitro* gas production techniques of five feeds

**Discussion**

As a result of feed fermentation, gas production is proportional to the digestibility of the feed, in particular to the amount of potential degradable fraction of a feed. Its increase depends on the proportion of DM available to be digested by rumen microorganisms. Gas from *in vitro* fermentation varies according to the forage species (Phelan *et al.*, 2015). Also, gas production or fermentation of feed may result from fibre content, plant second metabolite or power of rumen fluid (Njidda and Nasiru 2010). All forages were significantly different in terms of gas production. Mixing legumes with *Chloris gayana* significantly increased the gas production, ME and OMD of the mixtures. Among the mixtures, *Chloris* Desmodium showed the highest and *Chloris* Cratilia the lowest gas production. The
observed increase in gas production showed that *C. gayana* supplemented with legumes may have been due simply to a higher degradability of the legumes and increased availability of crude protein in forage legumes. Low crude protein in *C. gayana* might have acted as a limiting factor for microbial mass synthesis (Njida and Nasiru 2010).

Comparing the results from the two different methods of *in vitro* gas production and *in sacco* methods in terms of degradation kinetics showed similar patterns of the kinetic graphs for gas production and DM disappearance for *in vitro* gas production and nylon bag technique, respectively, for each feed. It is obvious that the shape of the curves is similar without any evident difference as an over- or under-estimation for a specific technique. This agrees with the previous experiments (Krizsan *et al.*, 2013) that showed a highly positive correlation between the results of the two methods used in the study. Furthermore, graphs from both studies appeared to agree that the fermentation of the grass-legume mixtures was not over at 72 h.

Based on data from *in vitro* gas production and *in sacco* techniques in the present study, mixtures of grass and legumes at the ration of 70:30 in DM basis has proven to have a higher rumen digestibility than grass alone. With a low level of production, the grass-legumes combination might be an affordable option to improve the production rather than feeding only grass diets. Results from the study showed that among all *C. gayana*-legume mixtures, *C. gayana-Canavalia* and *C. gayana-Desmodium* mixtures might be the most recommendable to the farmers due to their nutritional attributes, specifically, OMD, ME content and the dry matter disappearance.

**Acknowledgement**

The authors are grateful to EU Commission Horizon 2020 for the financial support through InnovAfrica project - 727201-2.

**References**


Closing feed gaps by winter forage production in Limpopo: What is the potential?

Lamega, S.A.¹, Komainda, M.¹; Hoffmann, M.P.²; Odhiambo, J.J.³; Ayisi, K.K.⁴; Isselstein J.¹

¹University of Göttingen, Department of Crop Sciences, Grassland Science; ²AGVOLUTION GmbH; ³University of Venda, Department of Soil Science; ⁴University of Limpopo, Risk and Vulnerability Science Center.

Key words: Forage crops; feed gaps; South Africa; APSIM.

Abstract
In southern Africa, livestock productivity in mixed crop-livestock systems is constrained by forage supply towards the end of the dry period. Opportunities to improve forage availability to close the temporal feed gap counteracting negative effects on production as well as on environment need to be explored. A promising option might be the planting of cover crops (CC) during the winter period. Hence, a field experiment was conducted in the Limpopo province (South Africa) during the autumn-winter period of 2019 at two sites (Syferkuil, Thohoyandu) with contrasting climatic conditions and soil type. We selected multi-functional C3 species – winter rye (*Secale cereal* L.) intensively used in the temperate region sown as pure stand and established at two sowing dates. We assessed forage production, soil water dynamics and nitrogen accumulation. In a second step, we tested the Agricultural Production Systems simulator (APSIM) model against the field trial data. We present here, preliminary results which show high potential growth when irrigated. Early planting of CC yielded the highest accumulated biomass (18 t DM ha⁻¹ and 7 t DM ha⁻¹ at Syferkuil and Thohoyandu, respectively) after 140 days while delayed planting (4 weeks after first planting) decreased biomass production. The model predictions rely heavily on pedo-climatic interactions which need further improvements.

Introduction
In temperate regions, cover crops, such as winter rye (*Secale cereale* L.), are grown for their function as catch crop to prevent nutrient losses along with their feed provisioning function. In contrast, in semi-arid and arid regions of the globe, agricultural production is constrained by soil degradation and low crop yields. Under such circumstances, multi-functional cover crops can give various agro-environmental benefits (Adetunji et al., 2020). In southern Africa, for instance, livestock productivity in mixed crop-livestock systems is constrained by forage supply towards the end of the dry period (Descheemaeker et al., 2018). Particularly in the Limpopo region in the northern South Africa, climate variability has led to a severe seasonality of forage supply that greatly reduces the efficiency of livestock production. According to Bell et al., (2016), this feed gap is generally a discrepancy between the livestock feed demand and the supply (in quality and quantity) of forage. However, to counter the negative effects of feed gap during the winter season, multi-functional C3 cover crops can be grown as a forage source. Integrating these cover crops in the feed-base systems may create opportunities for mixed farmers aside from relying on common traditional strategies such as herd size reduction. Performance of common temperate region cover crops in South Africa require a sophisticated evaluation before they can be used, which is attempted in the present study.

Material and Methods
We conducted field trials in the dry season (May – September) at two sites in the Limpopo Province of South Africa. The first experimental site was located in Thohoyandu (22°58’049.9” S and 30°26’016.8” E, 597 m above sea level) and the second site (Syferkuil) is located in Mankweng (23°50’001.5” S and 29°41’034.4” E, 1226 m above sea level). The soil type is classified as Rhodic ferralsol with high clay content and pH of 5.0 while the soil at Syferkuil is classified as Chromic Luvisol with pH of 6.8 (Rapholo et al., 2019). The present study was part of a larger two-factorial field experiment with the sowing date (two levels) and cover crop species (six levels) as factors. Only the rye treatment is considered in the present study. Cultivar ‘Bonfire’ was seeded...
at 100 kg ha⁻¹ with a row spacing of 15 cm on the 3rd May and 10th May 2019 in Thohoyandu and Syferkuil, respectively and the late planting dates were 31st May and 7th June 2019 at these sites. The experimental plots were 10 m² in size and set up in a randomized complete block design with four replications. Before sowing, phosphate was applied to all plots as superphosphate (10.5% P) at the rate of 20 kg P ha⁻¹. The dry season generally receives no rain; therefore, all plots were fully irrigated to assess the potential biomass yield. Soil properties to set up the APSIM model for each site were taken from Hoffmann et al., (2018) and Rapholo et al., (2019). To simulate the rye biomass, we modified the APSIM-wheat model as described in Chatterjee et al., (2020). To calibrate the model, the above-ground biomass was repeatedly sampled by manual clipping at soil surface using a 0.25m² quadrat and dried to constant weight. To analyse the accumulated rye biomass, a linear mixed-effects model was generated where the planting date, site, and their interaction were modelled as fixed factors and the block was modelled as a random effect. APSIM model predicted above-ground biomass was evaluated against observed data for each site and sowing date. Prediction was evaluated using the root mean square error (RMSE) and the Pearson’s correlation coefficient.

**Results**

The accumulated rye biomass was affected by planting date \((P<0.05, \ F\text{-value} = 4.33)\), site \((P<0.01, \ F\text{-value} = 25.37)\) and the interaction of planting date x site \((P< 0.05, \ F\text{-value} = 5.56)\). The difference between early sowing and late sowing was 66% at Syferkuil and 30% at Thohoyandu. The accumulated rye biomass at early planting was higher \((17698 ± 2023 \text{ kg ha}^{-1})\) at Syferkuil than Thohoyandu \((6873 ± 1426 \text{ kg ha}^{-1})\) (mean ± s.d.) (Figure 1).

![Figure 1: Mean (point) and standard deviation (error bars) of dry matter yield (kg/ha) of repeatedly sampled biomass as demonstrated by sites and planting dates (black) and simulated biomass production (red).](image-url)

Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods
The RMSE of 1122 (kg ha\(^{-1}\)) demonstrated that the APSIM modelled simulated rye biomass was predicted satisfactorily against a mean of 5588 (kg ha\(^{-1}\)) (Figure 2). However, a strong Pearson’s correlation coefficient of 0.9 (P<0.001) showed that sites and planting dates effect were captured by the model.

Discussion [Conclusions/Implications]
The dry matter yields for the two planting dates were higher in Syferkuil as opposed to Thohoyandu which could be explained by site-specific soil types. Though the clay soil type at Thohoyandu provides good water holding capacity, water in the top layer is more likely to be evaporated (Rapholo et al., 2019). Other studies reported low biomass yields which were associated with reduced precipitation in the growing periods in South Africa (Hoffmann et al., 2018; Muzangwa et al., 2013). However, here, low biomass recorded with the delayed planting can be attributed to shorter time periods for growing. The comparison of the simulated and observed biomass shows that APSIM was able to capture the effects of planting dates across sites (r = 0.9). The simulated biomass is therefore in good agreement with the observed field data. From an agronomic perspective, the cover crop appears promising as a feed-base strategy that could be employed to diversify the on-farm forage sources. According to Bell et al., (2016), introducing forage resources in a way to diversify the on-farm feed-base systems provide the opportunity to reduce feed gaps and increase stocking rates on farms. Nevertheless, further investigation is required, specifically regarding the feasibility of the production at rural level. The model simulation could offer the opportunity to explore site-specific conditions and assess the potential of integration of cover crops in the farming systems (socio-economic viability) against climate scenarios as demonstrated elsewhere (e.g. Descheemaeker et al., 2018) after sophisticated model calibration.

Acknowledgements
This paper is based on a research funded by the German Ministry of Education and Research (BMBF, SPACES II-Joint Project South African Limpopo Landscapes Network (SPACES II: SALLnet)). The authors acknowledge the help of student assistant Segolo Phasha and research assistant Kabisheng Mabitsela in collecting data.

References


Maintain forage yields in long- and short-term grasslands in Norway

Sturite, I; Maeland, T; Höglin, M.

1Norwegian Institute of Bioeconomy Research, Division of Food Production and Society; 2Department of Grassland and Livestock No-8860 Tjøtta, Norway; No-4353 Klepp, Norway

Key words: age of sward; fertilization, ploughing; reseeding

Abstract

Various reasons have been invoked explaining the low renovation activity in Norwegian grassland farming: swards are often located in marginal areas, ploughing and reseeding gives low or no yield in the renovation year, and it may be unprofitable to establish a new sward. The establishment of new leys can also prove difficult in seasons with unfavourable weather conditions. Thus, farmers prefer long-term or permanent swards as opposed to ploughed and reseeded swards. The hypotheses of this study is that under equal management conditions, permanent and temporary swards (leys) that are reseeded frequently are equally productive. We present results from an experimental field trial at Særheim (58°47′N 5°41′E), SW Norway, which was established 1968. The experiment includes grass plots maintained without ploughing for more than 50 years, and frequently (every 3 to 6 years) ploughed treatments. Three different fertiliser strategies are included: mineral fertiliser (210 N kg ha⁻¹) and cattle slurry in combination with mineral fertiliser (210 kg and 340 N kg ha⁻¹). In 2016, the frequently ploughed treatments and half of the 25-years-old sward was renewed by ploughing and reseeding with grass-clover seed mixtures. The second half of the 25-years-old sward was sod-seeded using perennial ryegrass (Lollium perenne) only in 2017 and grass-clover mixtures in 2019. Herbage yields and forage quality was determined after each of the three annual cuts. In the first year after reseeding, 2017, the leys had significantly higher forage yield than the 50- and 25-year-old permanent grasslands regardless fertilisation strategy. This difference between leys and long-term grasslands was evened out in the second production year. In 2019, the permanent grassland yielded significantly more than in the leys except in the plots, which received 210 kg N ha⁻¹ in combined form. There was no difference in herbage yield between swards that had been renovated by sod-seeding or by ploughing and reseeding.

Introduction

Improving grassland productivity and thereby improving livestock production is a main part of grassland management. Fertilisation, use of valuable forage species and improved grazing and harvesting practices are common measures to improve grassland productivity (Frame, 1992). Grassland renewal is mainly a reaction to a decline in yield and nutritive value (Kayser et al., 2018) e.g. after stressful environmental conditions reducing the proportion of desirable species in the sward. However, in general grasslands systems are rather stable. In Western and Northern Norway, a significant number of swards are more than 10 years old. Various reasons have been invoked to explain the low renovation activity in Norwegian grassland farming: swards are often located in marginal areas, ploughing and reseeding gives low or no yield in the renovation year, and it may be unprofitable to establish a new sward. The establishment of new leys can also prove difficult in seasons with unfavourable weather conditions and is threatened by low winter survival in the year of reseeding. Thus, farmers prefer long-term or permanent swards as opposed to reseeded swards. In recent years, interest in long-term grasslands has increased in Europe too due to the general need for reducing the costs of forage production and a need to maintain or increase soil carbon. Several studies have concluded that under equal management conditions, permanent and temporary swards are equally productive (Hopkins et al., 1990; Nevens and Reheul, 2003). However, in northern Norway, Nesheim (1986) found that dry matter yields (DMY) declined after the fifth year and 11-20 years old leys had the lowest DMY, whereas swards older than 20 years had intermediate yields. In SW Norway, Lundekvam and Myhr (1975) showed strong correlation between age of the grassland, weed
density and DMY. In their study, long-term grasslands produced high DMY in 15 years. Here, we present results from an experimental field trial at Særheim (58°47′N 5°41′E) in SW Norway. This trial, which has been maintained since 1968, includes plots which have been maintained without ploughing for more than 50 years, as well as frequently ploughed and reseeded treatments. The hypothesis is that under equal management conditions, permanent and regularly (every 3 to 6 years) reseeded swards are equally productive.

**Methods and Study Site**

The long-term trial was established at NIBIO research stations in SW Norway, Særheim, Rogaland (58.8°N 5.6°E 80 m asl.) in 1968. The soil was developed on morainic material. It has a humus rich well-defined plough layer overlying a moderately well-drained silty sand subsoil. Until 2016, the trials included four main-plot treatments with different sward ages established with three replicates per trial:

- **PG**: Permanent grassland established in 1968
- **S-PG**: Semi-permanent grassland established in 1992
- **LEY-6**: 6-year ley
- **LEY-3**: 3-year ley.

Various management regimes were included on sub-plots, including cutting-grazing regimes (with/without spring and autumn grazing) and mineral fertilizer only until 1992. Treatments with cattle slurry were included from 1992. Both ley treatments were ploughed prior to each 3- or 6-year reseeding.

In 2016 the experimental design was modified by splitting the main treatments, and S-PG was renewed either by ploughing (S-PGp) or direct sod-seeding (S-PGs). LEY-6 and LEY-3 were also ploughed and reseeded and production period extended to 12 (LEY-12) and 6 years (LEY-6), respectively. In 2016, a grass-clover mixture was used in all plots renewed by ploughing. In 25-year old S-PGs plots English ryegrass (*Lollium perenne*) was sown in 2017 and sod-seeded grass-clover mixture in 2019. Three different fertilisation practices included on sub-sub-plots. Nitrogen (N) applied in form of mineral fertiliser only (MF; 210 kg N ha⁻¹) and cattle slurry combined with mineral fertiliser (CS+MF; 210 and 340 kg N ha⁻¹). The plant biomass was harvested according common practice in the region, three times during the growing season. In 2017, however, only two cuts were performed because of excessive precipitation in the second part of growing season. The herbage yields and forage quality were determined after each cut. The data were analysed by general linear model and one-ways ANOVA.

**Results**

In the first production year, 2017, the frequently ploughed and reseeded leys had significantly higher forage yield than permanent (>50 years without ploughing) and semi-permanent (25 years) grassland, regardless fertilisation strategy (Figure 1). This difference between ley and long-term grasslands disappeared in the following year and in 2019, DM yields of PG treatments were significantly greater than for reseeded treatments S-PGs and LEY-6 (P<0.007) (not shown). Average DM yields for four production years and all treatments are showed in Figure 2. Under equal fertilisation practices, both long-and short-term grasslands produced equally large DM yield. There was no difference in DM yield between swards that had been renovated by sod-seeding or by ploughing and reseeding (Figure 2).

![Figure 1: Average DM yield in 2017 for permanent grassland (PG), semi-permanent grassland (S-PG) and reseeded ley in 2016 (LEY-6 and LEY12) fertilised with mineral fertiliser only (210 MF) or cattle slurry in combination with mineral fertiliser (210 CS+MF and 340 CS+MF).](image-url)
Fertilisation strategy significantly affected forage production. Particularly, treatment 210 CF+MF resulted in significantly lower forage DM yield (P<0.5) compared to treatment 210 MF and 340 CS+MF. On average for all production years the 210 MF treatment resulted in equal DM yields as the 340 CS+MF one (Figure 3).

Figure 2: Average DM yield for four forage production years and for permanent grassland (PG), semi-permanent grassland renewed by sod-seeding (S-PGs) and ploughing (S-PGp) and reseeded ley in 2016 (LEY-6 and LEY12) fertilised with mineral fertiliser only (210 MF) or cattle slurry in combination with mineral fertiliser (210 CS+MF and 340 CS+MF).

There were no differences in forage quality between treatments (data is not showed).

**Discussion [Conclusions/Implications]**

Our hypothesis, that under equal management conditions permanent and regularly reseeded (every 3 to 6 years) swards are equally productive, was supported. The 50 years old permanent grassland produced good quantity and quality of forage yield and even more in 2019 than particularly treatments of four years old leys. Assessment of botanical composition in PG showed that forage biomass contained more than 60% of cultivated grass species like perennial ryegrass, meadow fescue (*Festuca pratensis*), smooth grass (*Poa pratensis*) and timothy (*Phleum pratensis*) (data not showed). These are all species that can provide high yields under Norwegian conditions. The results throughout suggest that cultivated PG can maintain good and stable forage production under appropriate fertilisation practice over several decades (Figure 2). Our study also shows that sod-seeding can be a good alternative to ploughing, which may be beneficial for the climate as grasslands may store significant amounts of C (Soussana *et al.*, 2004). However, sod-seeding might unsuccess and then it might result in resource and yield loss. More research is needed to determine under which conditions sod-seeding will be successful and under which conditions ploughing before reseeding is needed (Rueda-Ayala and Höglind 2019).

In order to obtain acceptable forage yields, the nutrient availability for plant growth is important. The lowest level of N applied in spring as cattle slurry resulted in lower yields than when the same level of N was applied as mineral fertilizer, indicating that N from organic sources is little available just after application or partly lost by ammonia emission. However, fertilisation strategies that include cattle slurry might be a good management practise and might give more advantages than disadvantages in long-term.

In conclusion, our findings show that permanent grasslands are productive and can give good yields with good quality over several decades.

**Acknowledgements**

This work was funded by a grant from the Norwegian Research Funds for Agriculture and Food Industry (FFL/JA 255176) ‘Smart renewal of long-term grassland: towards higher productivity and profitability (LONGTERMGRASS). We thank Isak Drozdik and Bertinius Brattebø for skilful technical assistance.
References


Regeneration of old ungrazed old man saltbush (Atriplex nummularia) stands in south-west Australia

Bennett, S.J.¹, Low, SG.¹, Collins, D.² and Crouch, V.³

¹ School of Molecular and Life Sciences, Curtin University, Perth, WA 6102, Australia; ²Greening Australia Western Australia (GAWA), Perth. WA 6000, Australia; ³Corrigin Farm Improvement Group (CFIG), PO Box 2, Corrigin, WA 6375, Australia

Key words: fodder shrub, grazing, salinity, productivity, soil regeneration

Abstract
Many old man saltbush (Atriplex nummularia) stands were sown in the grainbelt of Western Australia for soil regeneration and salinity management up to 25 years ago, but have not been effectively grazed subsequently, such that the main feed available for sheep is above grazing height. The aim of the study was therefore to see if it was possible to return the old man saltbush stands to a productive grazing stand.

Two sites were chosen that had been sown up to 25 years previously in Goomalling and Corrigin, in the south-west of Western Australia. The sites were split into four treatments that would reduce the height of the stands and bring all grazing material back to less than 1.2 m (the maximum grazing height for sheep in Australia): cutting to 0.5 m, cutting to 1 m, rolling to ground level, and a uncut control. Available feed above and below 1.2 m was assessed before cutting or rolling and then four times over the next two years.

The results found that all three treatments removed feed above 1.2 m and that after 2 years the amount of feed below 1.2 m was increasing. The greatest feed available below 1.2 m was in the rolled treatment, followed by cutting to 0.5 m. Cutting old man saltbush stands to 1 m provides greater feed on the plants after cutting, but within one year of cutting some of the new feed is already above grazing height.

It is concluded there is potential to return old established stands of old man saltbush to a productive grazing stand.

Introduction
Old man saltbush (Atriplex nummularia Lindl.) is a saline-tolerant, halophytic woody shrub from the family Chenopodiaceae that is native to Australia. It occurs in the arid and semi-arid rangeland areas, and was widely recommended for sowing in the agricultural areas of southern Australia that were becoming unproductive for cropping (Barrett-Lennard, 2002). However, many plantings of old man saltbush sown 15 to 20 years ago were planted too close together for effective management and subsequently are now over-grown and too tall to be an effective feed resource for sheep. Close and over-grown saltbush also leads to limited regeneration of a pasture understorey, and thus poor biodiversity. This means that although they have been successful in the reclamation of degraded land in terms of potentially reducing soil erosion, rising salinity or waterlogging, they are not an economic resource for landholders and so have not been adapted as a profitable component of the farming system.

Currently landholders with old woody and overgrown old man saltbush plantings are unsure what to do with them, are thus considering removing them, plus wouldn’t plant anymore of their farm to fodder shrubs. However, this increases the risk of on-farm salinity and waterlogging increasing as the watertable rises with the removal of perennial summer-active vegetation from the system (Bennett & Barrett-Lennard, 2013). (Monjardino et al., 2010) have previously shown that if 10% of the farm is sown to perennial forage shrubs, farm profitability can be increased by an average of 24%, primarily through the provision of ‘out-of-season’ feed and the productive use of marginal soils. It is therefore not advantageous to landholders to remove their old man saltbush plantings, and there is an urgent need to determine methods of bring them back
into a productive and profitable component of the farming system.

The aim of the study was to; determine if old man saltbush plantings can be regenerated to form a useful resource, to determine the most effective method of regeneration, and to demonstrate that regeneration can increase and improve feed availability for livestock.

**Methods and Methods**

The trial consists of two sites sown approximately 15 to 20 years prior to the commencement of the trial; Goomalling (-31.307185, 116.831752) and Corrigin (-32.333748, 117.873180), Western Australia. Both sites are in the medium rainfall zone of Western Australia with a mean annual rainfall of 365 mm and were sown into sites that were becoming saline and unprofitable for cropping). The site at Goomalling is sown as two rows of old man saltbush, followed by two rows of river saltbush (Atriplex amnicola Paul G. Wilson), another endemic halophytic perennial shrub, with an 8 m gap between rows. The site at Corrigin was sown as three rows of old man saltbush, each 8 m apart, with an inter-row of 28 m (wide enough to be cropped), before the next set of three rows.

The trial at Goomalling was laid out with four treatments, each 120 m long, of fodder shrubs that comprised 2 rows of old man saltbush and 2 rows of river saltbush. The four treatments were a) rolled/ squashed to ground level, b) cut to 50 cm height, c) cut to 100 cm height, and d) left as the control. Each treatment row was split into four replicated sampling blocks (10 m) along each treatment, with 15 m between blocks. An initial assessment of available edible ‘food-on-offer’ biomass sampling of material of both old man and river saltbush was conducted on 4th April 2016, prior to the treatments being imposed using the ‘Adelaide’ method described by Andrew et al., (1976). For the purposes of this paper only the results of the old man saltbush will be reported.

The site at Corrigin was laid out with three treatments, each 120 m long, of fodder shrubs that comprised 3 rows of old man saltbush, 8 m apart. The three treatments were a) rolled/ squashed, b) cut to 50 cm height, and c) left as the control. Each treatment row was split into four replicated sampling blocks along each treatment, as above. No initial sampling of the biomass took place at Corrigin, but the initial biomass was estimated from the ends of each of the rows after the treatments were imposed on 4th April 2016 using the same method described above.

Food-on-offer biomass samples (Andrew et al., 1976) were taken from both sites in September 2016 to measure growth in each block over the late autumn and winter. Sites were sampled again in January and March 2017 to determine spring and summer growth in the treatments. Final cuts were taken in early July 2017 at Goomalling. This was not a scheduled sampling time, but due to the very dry start to the season in 2017 the farmer needed to use the study site for feed for his sheep. The site was therefore assessed for available feed before the sheep entered the site. The final assessments were taken in October 2017 at Corrigin, as initially planned. Sample dates for the trials at both sites are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Trial sites</th>
<th>Prior to treatments</th>
<th>Spring</th>
<th>Start of summer</th>
<th>End of summer</th>
<th>Winter</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goomalling</td>
<td>4/4/2016</td>
<td>30/10/2016</td>
<td>18/01/2017</td>
<td>23/03/2017</td>
<td>06/07/2017</td>
<td></td>
</tr>
<tr>
<td>Corrigin</td>
<td>4/4/2016</td>
<td>3/10/2016</td>
<td>14/12/2016</td>
<td>13/06/2017</td>
<td>10/10/2017</td>
<td></td>
</tr>
</tbody>
</table>

**Results**

The increase in available grazing biomass in old man saltbush below 1.2 m (Goomalling) and 1 m (Corrigin) in all treatments over the 2 years since the treatments were imposed is shown in Figures 1 and 2. In both the rolled/ squashed and cut to 0.5 m treatments the amount of feed available above 1.2 m (Goomalling) or 1 m (Corrigin) is negligible following the start of the experiment, highlighting that all the new growth is available to grazing sheep. At the Goomalling site in the treatment, cut to 1 m, the amount of feed above 1.2 m was negligible in the Oct and Jan measurements, but one year after it was cut, the amount of feed-on-offer above 1.2 m was not significantly different ($P>0.05$) to that recorded at start of the experiment. The decrease in the food-on-offer biomass available in the 6th July 2017 assessment, compared to the previous assessment in all treatments is thought to be due to leaf drop as a result of the dry start to the season.
At the Corrigin site both the rolled/squashed treatment, and the treatment cut to 0.5 m showed negligible feed-on-offer above 1 m in the assessments made in the initial year. In the two assessments made in 2017, the amount of feed-on-offer above 1 m had started to increase. However, the amount of feed-on-offer biomass below 1 m had increased significantly ($P<0.05$) in the treatment cut to 0.5 m. Although the amount of feed-on-offer biomass below 1 m had increased in the rolled/squashed treatment in 2017, it was not significantly different to that recorded in the control.

Figure 2: Feed-on-offer biomass available on old man saltbush above and below 1.2 m grazing height across the four treatments at Goomalling; a) control (not cut), b) cut to 0.5 m height, c) cut to 1.0 m height and d) plants rolled to ground. Sample date 4th April 2016 is before treatments were imposed.

Figure 3: Feed available on old man saltbush above and below 1.2 m grazing height across three treatments at Corrigin; a) control (not cut), b) cut to 0.5 m height, c) plants rolled/squashed to ground not shown). Sample date 4th April 2016 is before treatments were imposed.
Discussion [Conclusions/Implications]
The results of the study show that old plantings of old man saltbush can be regenerated to form a useful resource again. This is highlighted by the landowner at Goomalling requiring the site for grazing in July 2017 following a dry start to the season, as there was no traditional annual pasture available in July (G. White, Pers. Comm.). This is a time of year when sheep are typically grazing annual pasture legumes that regenerate following rains at the start of the growing season in autumn (Dear and Ewing, 2008). Traditionally old man saltbush was recommended as an out-of-season feed for the autumn feed gap, when summer stubbles have been exhausted, but annual pastures have not yet established sufficiently for grazing. However, more recent research has shown that old man saltbush can be a useful feed resource at different times of the year, including in winter as used at Goomalling (Bennett & Barrett-Lennard, 2008).

Although the trial was only run for two years, it is suggested that the most suitable treatments for saltbush regeneration, were those that cut the saltbush lower than the 1.2 m height that sheep can reach for grazing (Andrew et al., 1976), thus the treatments that either cut the saltbush to 0.5 m or rolled/squashed the saltbush to the ground. Although these treatments showed a slower recovery following the imposed treatments, even after two years the amount of feed above sheep grazing height was negligible, while the amount of feed below grazing height has increased significantly providing a valuable grazing resource that could be managed into the future as a profitable component of the farming system. It is recognised that this trial is limited as sheep were not included as part of the saltbush recovery, and that by using the old man saltbush as a valuable component of the grazing system the height of the saltbush should be maintained at a lower level.

To conclude, although Monjardino et al. (2010) modelled that by sowing up to 10% of a farm to perennial fodder shrubs, farm profitability could be increased by an average of 24% in medium to low rainfall mixed crop-livestock farms in Western Australia, this can only be achieved by using land that is marginal or unprofitable for cropping. Providing a method, such as described in this study, that landholders can use to convert unprofitable land, sown to saltbush for saline land regeneration, to a profitable component of the farming system with an out-of-season feed resource ensures that landholders retain their saltbush plantings, protecting land at risk of becoming saline for future generations.

Acknowledgements
Thanks to Wheatbelt Natural Resource Management for funding the trial (Project code SA01-R315), and to Geoff White and Lex Stone for hosting the trial sites for the research.

References


THEME 2: FORAGE PRODUCTION AND UTILIZATION

Topic: Forage and Animal Nutrition
Isolation and Identification of Lactic Acid Bacteria Strains and their Effects on the Fermentation Quality of Elephant Grass (Cenchrus purpureus) Silage

Azizza Mala 1,2, Babo Fadlalla1, Zhihao Dong1, Junfeng Li 1 and Tao Shao1

1Institute of Ensiling and Processing of Grass, College of Agro-grassland Science, Nanjing Agricultural University, Nanjing, China
2Environmental, Natural Resource and Desertification Research Institute, National Center for Research, Ministry of Higher Education, Khartoum, Sudan

Keywords: Elephant grass, Lactic acid bacteria, Isolates, Fermentation, Lactobacillus plantarum, Pediococcus acidilactic

Abstract
This study aims to isolate and identify lactic acid bacteria and examine their effects on the fermentation quality of elephant grass silage. The isolated strains were identified based on morphological, physiological and biochemical characteristics as well as 16S rRNA analysis. Three strains namely Pediococcus acidilactic (AZZ5), Lactobacillus plantarum subsp. Plantarum (AZZ4), Lactobacillus plantarum subsp. Argentoratensis (AZZ6) were isolated from elephant grass silage. Isolation of the microbes was done by serial dilution method. Three LAB and one commercial bacteria Lactobacillus Plantarum, Ecosyl MTD/1(CB)) were used as additives to fresh material of elephant grass. To follow the fermentation quality during ensiling, samples were taken on days 30, 60 and 90 of ensiling for chemical analysis. The strain AZZ5 was identified as Pediococcus genus while AZZ4 and AZZ6 were Lactobacillus genus. Compared to the control, all the isolates improved the silage quality of elephant grass silage. In conclusion, AZZ4 performed better among all inoculants.

Introduction
Elephant grass (Cenchrus purpureus) is a monocot C4 perennial grass in the Poaceae family, and it is among the highest yielding tropical grasses. Nevertheless, elephant grass is regarded as one of the most important tropical forages because of its high potential for biomass production, easy adaptation to diverse ecosystems and good acceptability by animals. A few homofermentative LAB commonly used in silage inoculants, including Lactobacillus acidophilus, Lactobacillus plantarum, Enterococcus faecium and Pediococcus acidilactici (Ennabar et al., 2003). According to a microbiological point of view to our knowledge, no information is accessible on the microbial ecology isolated from elephant grass silage, especially about the indigenous LAB and their effects on fermentation during ensiling. Currently, elephant grass has become more attractive due to its high yielding tropical grasses and good palatability for the animal, which can make it suitable for the LAB inhabit. For this reason, we chose elephant grass as research material for LAB isolation and selection. This study set out to isolate, screen and identify lactic acid bacteria from elephant grass and their effect on fermentation quality of elephant silage during the fermentation process.

Material and Methods
Isolation and screening LAB
Ten grams of elephant grass were blended with 90 ml of sterilized saline solution (8.50 g L−1NaCl). Each LAB colony was isolated and purified twice by streaking on MRS agar plates.

Extraction of lactic acid bacteria genomic DNA
Bacterial DNA was extracted according to the method of (Zoetendal et al., 1998) by a mini-bead beater. The genomic DNA concentration of each strain was determined by UV-VIS Spectrophotometer at 260 nm. The nucleotides sequences for the 16S rRNA gene were deposited to the GeneBank under accession numbers of AZZ4, AZZ5, and AZZ6 were KY584256, KY584255 and KY 584254 respectively.
Silage preparation

Strain AZZ4, AZZ5 and AZZ6 were chosen as additives at 6 log colony forming units (cfu)/g of fresh elephant grass. Experimental treatments included: control silage without LAB, elephant grass + AZZ5, elephant grass + AZZ4, elephant grass + AZZ6 and elephant grass + CB. Three silos from each treatment were opened after 30, 60 and 90 days of ensiling, respectively.

Chemical analysis

The WSC was measured by the anthrone method (Arthur 1977). NH3-N was determined by the phenol-hypochlorite procedure (Kleinschmit et al., 2005). The organic acid and ethanol contents of the silage were analyzed by Agilent HPLC 1260.

Results

16S rRNA Gene Sequence Analysis

After blasting the 16S rRNA sequence, Strains AZZ4 and AZZ6 were clustered in the genus Lactobacillus with 81% similarity among their 16S rDNA gene sequences, on the other hand, strain AZZ5 was clustered in the genus Pediococcus with 99% similarity in their 16S rDNA gene sequences.

**Figure 1:** Polygenetic tree showing the relative positions of strains AZZ4, AZZ5, and AZZ6 isolate from elephant silage and related species, as inferred by the neighbour-joining method using complete 16S rRNA sequences.

Effect of LAB isolates on pH, WSC, NH3-N of elephant grass during ensiling

Effect of LAB on fermentation quality of elephant grass is shown in Figure 2. The addition of lactic acid bacteria isolates caused a higher level of LA, resulting in more decrease in pH and ammonia content than the control.
**Discussion**

Differentiation between isolates of known species using phenotypic methods is inconsistently successful, while the reported use of 16S rRNA sequence analysis is considered a good approach to identify LAB strains at both the genus and species level (Björkroth *et al.*, 2002). However, some LAB species, for example, *L. plantarum* and *L. pentosushave* very similar 16S rRNA gene sequences, differing only by 2 bp (Hammes and Vogel 1995). Bacterial inoculants are added to forage at ensiling to stimulate lactic acid (LA) fermentation by accelerating the decrease in pH, thus improving silage preservation (McDonald *et al.*, 2002). All inoculants improved the ensiling fermentation as apparent from a faster decrease in pH of elephant grass silage which is consistent with previous studies (Fellner *et al.*, 2001).

**Conclusion**

Applying LAB isolates on elephant grass significantly influenced fermentation quality. The LA content increased by applying LAB isolates during ensiling. *L. plantarum subsp. plantarum* (AZZ4) had a better fermentation quality.

**Acknowledgments**

This work was partially supported by the National Natural Science Foundation of China (31672488) and the project of cultivation, processing and utilization of forage in high temperature and humidity area (2017YFD0502106).
Reference


Effectiveness of solarization pre-treatment for improvement of feed value of straws by white rot fungi inoculation

J. Njolomba1*, M. Hanada1*, S. Muyila1, N. Fukuma1, T. Neshida1, T. Sato1, M. Yamakawa2
1Faculty of Food Science and Agriculture, Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan
2Hokkaido Animal Research Organization, Hokkaido, Japan

Key words: Solarization; Lignin; white rot fungi; wheat straw

Abstract
The purpose of this study was to investigate whether solarization could replace pasteurization and autoclave sterilization in feeding value improvement of lignified feeds treated with white rot fungi. Wheat straws were chopped between 3-5cm length, soaked overnight, drained, placed in mushroom bags, and either solarized for 8 hours, or pasteurized at 100 °C for 60 minutes and or autoclaved at 121 °C for 20 minutes. A 200g sample of straw was treated with Pleurotus ostreatus (PO) and Pleurotus citrinopileatus (PC) at 5% spawn rate. Straws bags were incubated for 0, 30, 60 and 90 days at fluctuating temperature and humidity. Chemical composition of the wheat straws was then determined for evaluating effectiveness of solarization as heat pre-treatments for white rot fungi treatment. During solarization, the temperature inside the bags of straws ranged from 28.9 °C to 55.4 °C. And the air temperature was positively associated with the temperature in the bag with a correlation coefficient of \( R^2 = 0.85; P<0.01 \). After incubation ADL content in the straws were decreased across all heat pretreatments \( P<0.01 \). ADL loss in autoclaved, Pasteurization and solarization were 60%, 47.6% and 48.2%, respectively. Additionally, a higher loss of ADL was caused by PO compared to PC \( P<0.01 \). The results of the current studies suggest that solarization could be an alternative method for heat pre-treatment prior to white rot fungi inoculation. Better results could be obtained in tropical climate zones.

Introduction
Resources of cereal straws are enormous, however, their utilization as ruminant feed is limited due to their high lignin content (Sharma and Arora, 2013). In order to remove lignin from the straws, some physical, chemical and biological (Okano et al., 2006) methods of delignification have been proposed.

In contrast to physical and chemical methods, biological methods have been recognized as safe and environmentally friendly method for removing lignin from lignocellulose materials (Taniguchi et al., 2005). Treatment of wheat straw with white rot fungi (WRF) has been demonstrated to effectively remove lignin and improve their nutritional values (Tuyên et al., 2012). WRF can degrade lignin through production of extracellular ligninolytic enzyme - laccase, lignin peroxidase, manganese peroxidase, and hydrogen peroxide generating oxidases (Hatakka, 1994). To reduce the negative effects of competitor moulds and to promote lignin degradation by WRF enzymes, pasteurization or sterilization is required before inoculation (Bellettini et al., 2016). Heat pretreatment, such as autoclaving, hot water immersion and steam treatment have been proposed (Siqueira et al., 2012). Most of these methods require the use of expensive equipment such as a sterilizer and/or the use of fossil fuel-derived energy. Therefore, it has been difficult to upscale their practical use at least at a farm level. On the economical scale, the heat energy throw put for these techniques renders them inappropriate to rural communities in developing countries. Nevertheless, straw sterilization by autoclaving or pasteurization has been successful in culturing WRF for mushroom production as well as test treatments for animal feeding. Autoclaving of straw at 121°C for 60 minutes (Yamakawa et al., 1991) and pasteurization at temperature between 60 and 100°C (Kurtzman, 2010) have supported WRF growth and eventual lignin degradation in straws.
Solarization might be effective to supress the negative effects of competitor moulds prior to spawning. Solar energy is sustainable and does not emit carbon dioxide like fossil fuels. Saritha and Pandey (2010) reported that solarization heat pre-treatment was effective on paddy rice for oyster mushroom production. Milstein et al., (1987) used prototype solar cookers to pasteurize wheat straw and the heat generated was adequate to reduce mould contamination. These facts suggest that solarization may suppress contaminant microorganisms attached to the cereal straws and grow WRF dominantly in it. However, there are few studies on the effectiveness of solarization for straws met for WRF inoculation as a way to upgrade its feeding value. Thus, in this study we compared the effects of 3 heat pre-treatments, solarization, pasteurization in steel pots and sterilization with autoclave, on the nutritional value improvement of wheat straw by white rot fungi inoculation.

Methods and Study Site
The study experiment was carried out at Obihiro University of Agriculture and Veterinary Medicine Obihiro, Northern Japan. Obihiro lays on the latitude 42°55.3’N; Longitude 143°12.7’E; with an average annual temperature of 6.6°C and a variation in temperature throughout the year of 29.2°C.

Pleurotus osteratus (Strain: TMIC30026; PO) supplied from Japan Kinoko Research Centre Foundation and Pleurotus citrinopileatus (Strain: HfpriPc82-1; PC) supplied from Hokkaido Research Organization Forest Products Research Institute were used in the study. Both species were grown and maintained on malt extract agar medium in an incubator. The general source of variation was method used and by the type of white rot fungi species, and incubation time.

Wheat straw (Triticum aestivum L) was chopped between 3-5 cm length and socked overnight. And the straws were left to drain of excess water. A 200 g of the wheat straw was packed in a mushroom bag of 10 x 30 cm and then subjected to heat treatment. Heat pre-treatment was performed in three ways: solarization, the mushroom bag was left on asphalt pavement for 8 hours on a sunny day. Both outside and inside temperature of the bag were recorded at hourly interval with a thermos recorded. For pasteurization, the bags were put in a steel pot with water and heated to 100 ºC for 60 minutes. In addition, other bags were autoclaved at 121°C- 15psi for 20 minutes. Popcorn grain spawn of PO or PC was added into the mushroom bag at 5% (w/w) of wheat straw. The inoculated bags were immediately sealed and incubated at fluctuating temperature and humidity for 0, 30, 60 and 90 days in the incubation compartment. However, relative humidity in the compartment was not allowed to drop to below 50% by placing a tray of water in the compartment. After incubation, the fungal growth was ceased by oven drying the straws at 60°C for 48 hours. Four bags were prepared for each heat pre-treatment, fungi species, and incubation time.

Dried wheat straws, samples were ground to pass a screen of 1.0 mm. Dry matter (DM) content was determined by drying at 135°C for 2 hours in an air forced oven-DS 400 Yamato scientific co. Ltd. Crude ash was determined by combustion for 3 hours at 600 °C in an electric muffle furnace. Neutral detergent fiber (aNDFom), acid detergent fiber (ADFom) and acid detergent lignin (ADL) were measured by the method of (Van Soest et al., 1991). aNDFom was determined by adding heat stable alpha amylase (Sigma A3306). Cellulose was calculated as the difference between ADFom and ADL, while hemicellulose contents of the samples were computed as difference between aNDFom and ADFom. The crude protein content was determined by Kjeldahl method. The rate of losses of DM and other nutrients after incubation compared to before incubation were calculated using the following equations, assuming that ash content in the wheat straw did not change during the incubation period.

Rate of Dry matter loss (%) = [1-(A1/A2)] *100

Where A1 is the ash content (%) in the wheat straw at the beginning of incubation,

and A2 is the ash at the end of incubation.

Rate of nutrient loss (%) = [1-((A1/A2)*B2/B1)] *100

Where B1 and B2 are nutrients content (%) in the wheat straw at before and after incubation.

The SAS program JMP Student edition (version 14.1.0) was used to analyse the data in a full factorial design with four replicates per treatment per given period of incubation time, sterilization method used and by the type of white rot fungi inoculated. The general source of variation was heat pre-treatment, incubation period and white rot fungi effects. Multiple mean comparison tests (Tukey’s test) were performed to compare the heat pre-treatment methods, and incubation periods, while the student t-test was used to compare the
Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

delayed by competing bacterium in the early stage may be that the growth of the white rot fungi was treatment compared to autoclaving treatment. It of decrease of ADL was lower in solarization heat treatment. However, magnitude of wheat straw by white rot fungi even with the possibility of improving the feeding value for WRF inoculation. These results indicate treatment can be used to disinfect wheat straw before inoculation, indicating that the solarization in the wheat straw preheated with solarization decomposed by the basidiomycete treatment even higher in ADL contents of the wheat straw after incubation were decreased in all heat treatments (P<0.01). Moreover, The ADL content after incubation in PO was lower than in PC (P < 0.01). Cellulose content in the wheat straw was slightly increased in autoclaved treatment, while a decrease of the cellulose content was observed in solarized and pasteurized incubated wheat straw (P<0.01).

The rate of ADL loss after incubation in autoclaved, pasteurization and solarization were 60%, 47.6% and 48.2% respectively. ADL loss after incubation was lower with the solarization and pasteurization treatments than the autoclaved treatment (P < 0.01). The rate of ADL loss after incubation was higher in the straw inoculated with PO than with PC (P<0.01). Cellulose losses were 21.6%, 23.4% and 29.5% for autoclaved, pasteurized and solarized incubated straw respectively. Regardless of the heat pre-treatment method, the cell wall fractions were degraded in the similar manner by WRF inoculation. The magnitude rate disappearance was highest in hemicellulose, ADL and cellulose in that order (P<0.001) across all heat pre-treatments.

Discussion
It has been said that pre-treatment requires a minimum temperature of 60-65 °C or higher (Kurtzman., 2010), but the solarization temperature did not reach 60 °C in this study. However, the mycelium grew and the ADL was decomposed by the basidiomycete treatment even in the wheat straw preheated with solarization before inoculation, indicating that the solarization treatment can be used to disinfect wheat straw for WRF inoculation. These results indicate the possibility of improving the feeding value of wheat straw by white rot fungi even with solarization heat treatment. However, magnitude of decrease of ADL was lower in solarization treatment compared to autoclaving treatment. It may be that the growth of the white rot fungi was delayed by competing bacterium in the early stage of incubation due to insufficient suppression, compared to the basidiomycete pre-treatment in autoclaved wheat straw. To suppress competition with other bacteria in the early stage of incubation, it may be necessary to raise the inside temperature of the bag to near 60°C or slightly higher during solarization treatment. A positive correlation was found between the outside temperature (Y) and the temperature inside the bag (Y) during solarization, and a significant linear equation was obtained (Y = 3.05X – 38.38). According to this equation, the ambient temperature needs to be 32°C or more to make the temperature inside the bag reach 60 °C or more. The days when the outside temperature is above 32°C are limited in temperate regions, but not uncommon in tropical regions. Therefore, solarization treatment would be a suitable preheat treatment for tropical regions. However, it seems that the relationship between the ambient temperature and the temperature in the inside the bag differs depending on several other factors such as the material and colour of the bag, the amount of straws to be put in the bag, the packing method as well as moisture content of straw at setting time. Different, ways of increasing the inside temperature of the bag during solarization could aid reduction in the competing microorganisms that may flourish during incubation period. Saritha and Pandey (2010) have suggested that merely covering wet paddy rice straw with a transparent polythene on flat surface could raise the temperature of straw in the upper 5cm layer to 59°C. Also reducing the volume of the straw could aid effective heat penetration of the straw that could reduce microbial level, and minimize contamination during incubation.

Under the present culture conditions and keeping in mind of minimum nutrient losses, PO showed higher ADL degradation and lower cellulose consumption ability than PC. This entails that the optimal temperature for increasing the ADL degradation ability differs depending on the type of WRF. Previous studies (Bellettini et al., 2016) have suggested that P. citrinopileatus grew well in a range of between 24-29 °C compared to P. ostreatus that has the ability to colonize substrate in the ranges of 5-35°C. For our current studies, incubation temperatures in the compartment were between 13.8 °C to 25.5 °C which probably could have contributed to low colonization of wheat straw resulting in lower ADL degradation in PC treated straw.

The magnitude rate disappearance during the incubation was higher in hemicellulose than in ADL in this study. Yamakawa et al., (1991) reported that WRF degrade hemicellulose from early stages of incubation while the significant
ADL degradation commences after completion of spawn growth. From the viewpoint of improving the feeding value of straws, it is desirable that the ADL disappearance rate be higher than that of hemicellulose and cellulose. It’s imperative to use species of white rot fungi that have a superior capacity of preferentially degrading lignin beginning at the vegetative stages of growth (Tuyen et al., 2012).

Conclusions
In summary, solarization could be an alternative method for heat pre-treatment before WRF inoculation under high ambient temperature conditions. However, more ADL in the wheat straw was decomposed in autoclaving compared with solarization. Solarization could be further studied for integration and refinement to form a low cost, most effective and viable substrate disinfection method compared to autoclave and pasteurization.

Acknowledgement
The authors wish to JICE/JICA – Africa business education initiative for youth for their unwavering support and sponsorship during the course of this study.

References


The CROPGRO Perennial Forage Model Simulates Productivity and Re-growth of Tropical Perennial Grasses

Boote, K.J.; Pequeno, D.N.L.; Alderman, P.D.; Rymph, S.J.; Lara, M.A.S.

1 University of Florida; 2 CIMMYT, Mexico; 3 Oklahoma State University; 4 Land-O-Lakes, Wisconsin; 5 University of Lavras, Brazil

Key words: Forage simulation model; Perennial grasses; Regrowth; Climatic effects

Abstract
This paper introduces the CROPGRO Perennial Forage model (CROPGRO-PFM) and describes its ability to simulate regrowth dynamics and herbage production of Brachiaria and Panicum as affected by harvest management and weather. The model simulates regrowth, herbage harvests, percent leaf, and herbage protein of perennial forage grasses and legumes over multiple seasons. It can regrow from zero LAI (after harvest) based on use of carbohydrate and N reserves in storage tissues; however, the amount of residual stubble and residual leaf area index (LAI) are also important for rapid regrowth and productivity. The model is publically available for download from DSSAT.NET.

Introduction
Perennial tropical grass species such as palisadegrass (Brachiaria) and guineagrass (Panicum) are important pasture grasses worldwide and are affected by management, fertilization, soils, and weather. Crop growth simulation models can be used as tools to evaluate forage production response to management strategies, soils, and weather variation. The CROPGRO Perennial Forage model, released with DSSAT V4.7 software (Hoogenboom et al., 2017), is capable of predicting herbage harvests, herbage protein, and re-growth of perennial forage grasses and legumes over multiple seasons. The model was converted from the annual CROPGRO model (Boote et al., 1998) to a perennial model by Rymph (2004) by adding a storage organ (rhizome, taproot, crown) with carbohydrate and N storage pools that provide the ability for re-growth despite zero LAI caused by harvest, severe drought, or freeze-loss of all leaf tissue. The model includes seasonal dormancy, freeze thresholds, and rules for partitioning to the storage organ. Rules for dormancy, freeze thresholds, partitioning, re-growth, productivity, mobilization of carbohydrate and nitrogen from storage pools to drive re-growth, and re-fill of storage pools are included in “species” and “cultivar” files. This perennial forage version, as released in the DSSAT V4.7, has species/cultivar files for Marandu (Brachiaria), Tifton-85 Bermudagrass (Cynodon), Panicum maximum (Tanzania), and alfalfa (Medicago sativa). The model requires a read-in file called “MOW” that specifies the harvest dates, the residual live stubble (kg/ha), associated percent leaf, and a hypothetical “re-set” leaf number on tillers. The model will start from seed or vegetative cutting. The model simulates daily dynamics of soil water, soil C, soil N balance, and growth response to weather, water stress, N deficits, and forage management practices. It uses the DSSAT-CENTURY soil C module (Gijsman et al., 2002) and re-cycles N from senesced litter. Simulated productivity and re-growth dynamics of Marandu, and Panicum maximum over multiple seasons are illustrated for Brazilian conditions.

Methods and Study Site
Palisadegrass (Brachiaria brizantha) cv. Marandu was grown during April 2011 to April 2013 on a highly fertile Kandiudalfic Eutrudox in a field at the University of Sao Paulo “Luiz de Queiroz” College of Agriculture in Piracicaba, Sao Paulo, Brazil (22°42’S, 47°30’W; 546 m a.s.l.). Treatments were two harvest frequencies, 28 day and 42 day, at rainfed or irrigated conditions. See Pequeno et al., (2014, 2018) for details of harvest handling, irrigation, weather, and N fertilization (400 kg N/ha per year). Forages were harvested at 10-cm stubble height from two 0.75-m² quadrats, and separated into leaf, stem, and dead material.
LAI was measured. Living stubble mass and corresponding percent leaf were measured periodically, because stubble mass and percent leaf are required inputs to the MOW file. Herbage yield corresponds to live leaf and stem, while the reported shoot mass is the sum of herbage plus stubble mass. Interpolation of stubble mass was required between sample dates, because stubble mass was not measured on all dates.

Guineagrass (*Panicum maximum*) cv. Tanzania was grown under irrigation at the same soil and site as described above, during December 2002 to April 2004. See Lara *et al.*, (2012) for details on management, irrigation, weather, and N fertilization (250 kg N/ha per year). Forage from three 0.5- by 2.0-m quadrats was clipped at 35-cm height on a 35-day harvest schedule (63-day in winter). Forage mass was separated into leaf, stem, and dead materials. LAI was measured weekly with LI-COR LAI-2000 plant canopy analyzer. The living stubble mass and corresponding percent leaf were measured three times during the study.

The weather, soils, and management information were provided as inputs to the CROPGRO-Perennial Forage model, release version as V4.7 (Hoogenboom *et al.*, 2017), with parameters as calibrated by Pequeno *et al.*, (2014, 2018) and Lara *et al.*, (2012). Model simulations were compared to observed shoot dry matter, leaf dry matter, stem dry matter, percent leaf, and crude protein (Lara *et al.*, 2012; Pequeno *et al.*, 2014).

**Results**

Simulated shoot growth and herbage production of Marandu:

The CROPGRO-PFM model was able to successfully simulate the shoot growth dynamics of Marandu palisadegrass over two years for the 28-day and 42-day harvest frequencies for rainfed and irrigated conditions (Pequeno *et al.*, 2014). Figure 1A illustrates the simulated shoot mass over time for the 42-day frequency treatment under irrigation. It is important to note that the baseline in the figure is the stubble mass (with a few sample dates showing, along with interpolation), and the sudden drop in the shoot mass corresponds to the herbage harvest (back to the stubble mass left). Figure 1B illustrates the simulated herbage mass for the 42-day frequency under irrigation.

**Simulated shoot growth and herbage production of Tanzania:** Figure 2A shows the CROPGRO-PFM model simulations of shoot growth dynamics of Tanzania guineagrass over 11 cycles over 1 ½ years under irrigated conditions (Lara *et al.*, 2012). Figure 2B shows the simulated percent leaf (of the total shoot) over time, showing how the percentage leaf drops with each harvest (to baseline percent leaf in stubble), and recovers after each cutting cycle.
Figure 2: Simulated compared to observed A) leaf and shoot mass and B) leaf as a percentage of shoot for Tanzania guineagrass for 35-day harvest frequency during 11 cycles over 1 1/2 years at Piracicaba, Brazil.

Discussion [Conclusions/Implications]
Simulated shoot growth and herbage production of Marandu: The CROPGRO-PFM model was able to successfully simulate the shoot growth dynamics of Marandu palisadegrass over two years for the 28-day and 42-day harvest frequencies for rainfed and irrigated conditions (Pequeno et al., 2014). Figure 1A illustrates the simulated shoot mass over time for the 42-day harvest frequency under irrigation. The model responds to lower temperature during the winter season, as can be seen in the smaller re-growth increment. During model calibration, these data assisted Pequeno et al., (2014) in setting the base temperature for leaf photosynthesis to 6.2°C. Likewise, the herbage mass (Figure 1B) shows clearly the reduced production during the cooler winter months. The herbage mass (vertical bar in Figure 1B) corresponds to the extent of the drop in the shoot mass in Figure 1A. Pequeno et al., (2014) evaluated the effects of harvest frequency, residual stubble, and percent leaf of the stubble (the latter two affect the LAI after harvest). They found that high frequency harvesting, e.g. every 14-days, reduced annual production, and that the combination of stubble mass and percent leaf of stubble affected residual LAI. The residual LAI for brachiaria should be above 0.7 to 0.8 for good recovery and maximum annual herbage production. Residual LAI less than 0.7 slowed recovery after harvest and reduced annual production.

Simulated shoot growth and percent leaf dynamics of Tanzania: The CRGPOR-PFM model successfully simulated leaf and shoot growth dynamics of Tanzania guineagrass over 11 cycles under irrigated conditions (Figure 2A) (Lara et al., 2012). As expected, the simulated percent leaf (of the total shoot) over time showed that the percentage leaf dropped after each harvest (to baseline percent leaf in stubble), and recovered after each cutting cycle. This is consistent with the knowledge that herbage harvest removes more leaf than stem mass, and that early re-growth (in the model and reality) emphasizes partitioning to leaf rather than stem (this partitioning function response is set in the species file).

Potential use of the CROPGRO Perennial Forage Model: The model can be used to evaluate perennial forage production responses to weather, management, fertility, and irrigation. We have used the model to simulate additional data sets on Brachiaria and Panicum as well as other perennial forage species including bermudagrass (Pequeno et al., 2014), alfalfa (Malik et al., 2018), and ryegrass (unpublished work) with good success. The model is publically available for download from DSSAT.NET (Hoogenboom et al., 2017).

Acknowledgements
We wish to acknowledge the in-kind support and interaction with DSSAT modelers (DSSAT Foundation) and many Brazilian visiting scientists who collected data and assisted in model improvement.
References


THEME 3 - LIVESTOCK PRODUCTION SYSTEMS

Topic: Utilization of Grasslands/Rangelands
On the move – Do domestic and wild ungulate species distributions overlap in the Mongolian Gobi?

Michler, L.M.¹; Kaczensky, P.²; Ganbaatar, O.³; Treydte, A.C.²

¹Department of Ecology of Tropical Agricultural Systems, University of Hohenheim, Germany
²Department of Forestry and Wildlife Management, Inland Norway University of Applied Sciences, Norway
³Protected Area Administration, Takhin Tal, Gobi Altai Province, Mongolia

Key words: GPS Tracking; Habitat Overlap; Herder Movement Strategies; Wildlife-Livestock Interaction

Abstract
In the Great Gobi B Strictly Protected Area (SPA), wild and domestic ungulates seasonally share the forage of the semi-desert and desert habitat. Around 130 herder families are grazing their livestock, mainly goats and sheep, in the protected area in winter. Wild ungulates of global significance in Great Gobi B SPA include the reintroduced Przewalski’s horse (*Equus ferus przewalskii*), which had previously been extinct in the wild. To determine potential habitat overlaps between Przewalski’s horses and livestock, we mapped the movements of 19 livestock herds monitored via GPS collars and ranger observations of Przewalski’s horse herds over a one year period from September 2018 to August 2019. We additionally conducted focus group interviews with nomadic herders about their rangeland management. We found that pasture use in and around the Great Gobi B SPA is still following the nomadic tradition, with herders moving camp locations on average eleven times per year, depending on forage availability. Our results show that the range of Przewalski’s horses and livestock mostly overlap around permanent and ephemeral water points. However, the same resources are used in different seasons. The protected area was recently expanded to twice its size, now also including additional herder households and traditional pastures. For the ongoing discussion about concerning the new zonation of the enlarged protected area it is important to consider both, herder and wildlife movements patterns, to meet the conservation goals of the protected area but also meet the needs of the traditional pastoral herding community.

Introduction
Nomadic pastoralism has been practiced worldwide for millennia as an adaption to temporal and spatial environmental variability (Dyson-Hudson 1980). The mobility of herders and their livestock is a livelihood strategy especially practiced in arid regions high in biodiversity but with overall low biomass productivity (Berzborn and Solich 2013). Biodiverse areas inhabited by livestock are often located in close vicinity to protected areas leading to interactions between wild and domestic ungulates (Du Toit et al., 2012). The rural economy of Mongolia is mainly based on livestock production by a semi-nomadic herding tradition (Fernandez-Gimenez 1999). To meet the nutritional needs of their livestock, herders have to move over long distances and cover large areas of grazing land, which can also include protected areas (Bedunah and Schmidt 2004; Fernandez-Gimenez and Batbuyan 2004). In many arid regions worldwide livestock share pasture resources with wild equids (Moehlman 2002). In Central Asia, the Przewalski’s horse (*Equus ferus przewalskii*) became extinct in the wild and the range of Asiatic wild ass (*Equus hemionus*) shrank dramatically (Feh et al., 2002; Kaczensky et al., 2007). One of the key concerns for the conservation of wild equids in Mongolia is the unprecedented increase in livestock numbers (Šturm et al., 2017) morphological and behavioural traits resulting in different dietary niches. Wild equids are a rather uniform group of large herbivores which have dramatically declined in numbers and range. Correlative evidence suggests that pasture competition with livestock is one of the key factors for this decline, and the situation may be aggravated in areas where different equid species overlap. The Dzungarian Gobi is currently the only place where two wild equid species coexist and share the range with the domesticated form of a third equid species. In the winter-cold Gobi
desert pasture productivity is low, highly seasonal, and wild equids additionally face increasing livestock densities. We used stable isotope chronologies of tail hairs to draw inferences about multi-year diet seasonality, isotopic dietary niches and physiological adaptations in the Asiatic wild ass (khulan). For present day Central Asia, it is estimated livestock by far dominates the ungulate biomass and wild ungulates account for <5% (Berger et al., 2013)humans have replaced large carnivores in most areas, and human influence not only exerts striking ecological pressures on biodiversity at local scales but also has indirect effects in distant corners of the world. We suggest that the multibillion dollar cashmere industry creates economic motivations that link western fashion preferences for cashmere to land use in Central Asia. This penchant for stylish clothing, in turn, encourages herders to increase livestock production which affects persistence of over 6 endangered large mammals in these remote, arid ecosystems. We hypothesized that global trade in cashmere has strong negative effects on native large mammals of deserts and grassland where cashmere-producing goats are raised. We used time series data, ecological snapshots of the biomass of native and domestic ungulates, and ecologically and behaviorally based fieldwork to test our hypothesis. In Mongolia increases in domestic goat production were associated with a 3-fold increase in local profits for herders coexisting with endangered saiga (Saiga tatarica. In Mongolia, reintroduction of the Przewalski’s horse started in two locations simultaneously in 1992, one being the Great Gobi B Strictly Protected Area (SPA) where the last wild Przewalski’s horses were observed until the late 1960s (Kaczensky et al., 2017a)”plainCitation”:(Kaczensky et al. 2017. Great Gobi B SPA was created to conserve wild equids but also allowed for the continuation of winter grazing by traditional nomadic pastoralists at pre-defined locations. Hence the range of livestock and Przewalski’s horses overlaps seasonally. The aim of this study was to gain a better understanding of pasture use by local pastoralists and evaluate when and to what degree their range overlaps with that of the reintroduced Przewalski’s horse population. We expected seasonal differences in the overlap of Przewalski’s horses and livestock due to the prevailing nomadic herding tradition. Our data provides the first detailed analysis of herder movements in the Great Gobi B SPA and it is expected to guide zoning of the newly extended Great Gobi B SPA and other management decisions aiming to support traditional nomadic pastoralism in the region.  

Study Site and Methods
Great Gobi B SPA was established in 1975 and originally stretched over 9,000 km², but was enlarged to around 18,000 km² in May 2019. It is located in south-western Mongolia and is dominated by semi-deserts and deserts habitats with poorly developed soils (Wehrden et al., 2006). The climate is characterized by short hot summers and long cold winters, and highly variable in precipitation averaging 96 mm rainfall per year (Kaczensky et al., 2008)”plainCitation”: ”(Kaczensky et al. 2008. The flagship species of the Great Gobi B SPA is the Przewalski’s horse (Equus ferus przewalskii) numbering around 300 Przewalski’s horses, the Asiatic wild ass (Equus hemionus) estimated to number around 9,000 animals, and the goitered gazelle (Gazella subgutturosa) estimated to number around 14,000 animals (Kaczensky et al., 2017b). These plains ungulates share the protected area with domestic livestock of around 130 nomadic herder families, primarily in winter. Herders in the Great Gobi B SPA keep goats (Capra aegagrus hircus), sheep (Ovis aries), but additionally have cows (Bos taurus turano mongolicus), horses (Equus ferus caballus), camels (Camelus bactrianus) and yaks (Bos grunniens). Only sheep and goats are accompanied by a herder on a daily basis while large stock grazes unaccompanied. Our study focussed on sheep and goat because they are by far the most numerous livestock and also constitute the most important source of income for local herd. The protected area in its original border consisted of a core zone with no human use allowed and a limited use zone plus, the protected area was surrounded by a buffer zone (Kaczensky et al., 2004). Zoning of the extended area of the Great Gobi B SPA is in progress.  

In total, we equipped 19 livestock herds with GPS collars between September 2018 and August 2019 which recorded GPS positions at 30 min intervals between 7:00 and 22:00. We installed GPS collars on male goats between the age of 3 to 5 years. Based on the GPS tracking data we manually identified the camp sites of the herder families with QGIS (2.18). Great Gobi B SPA rangers obtained location data of Przewalski’s horse groups as they checked on Przewalski’s horse groups on a weekly basis and marked their position on a grid map (personal report Ganbaatar, 2021).  

In autumn 2019, we conducted four focus group interviews with a total of 36 local herd using Great Gobi B SPA. During the focus group interviews we discussed the preferences of
livestock for certain plants and the decision-making process behind camp site selection. To identify the most commonly used vegetation units by herders for their camp and grazing sites we used the vegetation map by Wehrden et al., (2006). The five major plant communities of the Great Gobi B SPA are *Stipa* spec. grasslands, and shrubby units of *Caragana* spec., *Nanophyton erinaceum*, *Reaumuria soongorica* and *Haloxylon ammodendron*. The livestock herd movements were plotted on the vegetation map to identify the most commonly vegetation units used by herders and their livestock and Przewalski’s horses.

**Results**

**Camp sites by herders in and around the Great Gobi B SPA**

According to our interviews, the main reason for herders to move their livestock was the rangeland quality. On the one hand, they claimed it was important to find sufficient forage resources to fatten the livestock, but on the other hand that moving also contributed to protecting the rangeland from overexploitation. Herders in and around the Great Gobi B SPA used on average 11 (± 3) camps per year, with 2 (± 1) different summer camps and 3 (± 1) winter camps. Winter camps showed the highest intensity of use (mean = 40 ± 31 days), while herders only stayed 27 (± 23) days at summer camps. The intermediate camps in spring (mean = 3 ± 2) and autumn (mean = 3 ± 1) were frequently changed with an average use of 22 (± 16) days in spring and 23 (± 12) days in autumn. Herders in the western part of the Great Gobi B SPA travelled more than 120 km between their summer and winter camps and stayed only inside the protected area between November and March. Herders in the eastern part covered a distance of around 70 km between summer and winter camps and stay from September to May in the protected area (Figure 1).

Herders often erected their camps close to smaller mountains and hills, which shelters the camp from the wind (our own observation). According to the herders, *Stipa* grasslands and specifically *Stipa gobica*, *Stipa glareosa* and *Allium mongolicum* are the most important fodder plants throughout all seasons. The shrubby plant communities are mainly important for livestock during winter months. Summer camps in the North are located at higher altitudes, offering relieve from the heat of the Gobi, biting insects and guaranteeing access to fresh water from mountain streams. During winter, areas sheltered from the wind and near areas where the wind blows away the snow cover to expose vegetation are the main reasons selection criteria for suitable camp locations. Intermediate season camps in spring and fall are located near permanent and ephemeral water points providing drinking water for people and livestock. Moving to spring camps is primarily motivated by the start of the growing season, while autumn camps are chosen in areas where vegetation availability is still high to fatten the animals before winter.

**Figure 1:** Map of the Great Gobi B Strictly Protected Area in Mongolia showing seasonal herder camps (triangles). Grey arrows illustrate the seasonal movements between summer camps in the North and winter camps in the South. Purple dots visualize grid-based Przewalski’s horse monitoring data in the years 2018 and 2019 recorded on a weekly basis. The dotted red line shows the extended protected area border (since May 2019), the black line shows the previous protected area border.
Przewalski’s horses avoiding areas of livestock
use

Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods

The Przewalski’s horses are rather conservative
in their movement patterns, stay close to water,
and do not show seasonal migrations (Ganbaatar
2003, Kaczensky et al., 2008). The range of
the Przewalski’s horses in 2018-2019 was still
focussed around the main release site in the NE
part of Great Gobi B SPA and a secondary release
site in the North-western part. Only a rather small
part of their range is within the core zone of the
original Great Gobi B SPA. In the NE part, the
Przewalski’s horse range overlaps primarily with
intermediate camps utilized in spring and fall.
Przewalski’s horses in the West hardly overlapped
with herder camps at all. Przwewalski’s horse
make intensive use of the Takhi us oasis in the
west and Khonin us oasis in the east, two areas
where herder camps are strongly discouraged.

832

Discussion
In line with Kaczensky et al., (2007)”plainCitat
ion”:”(Kaczensky et al. 2007, our results show
that Przewalski’s horses seem to avoid areas
of livestock presence and wildlife-livestock
interactions are negligible during summer months
when herders move to the summer pastures
high in the Altai Mountains (Kaczensky et al.,
2008)”plainCitation”:”(Kaczensky et al. 2008.
We found that, in times when livestock is absent,
the Przewalski’s horses use the same water points
that were visited by herders and their livestock
during spring and autumn. In other areas of
Mongolia, wild ungulates are often negatively
affected by the presence of herder camps (Olson
et al., 2011; Young et al., 2011)we surveyed
Mongolian gazelle (Procapra gutturosa. However,
reintroduced Przewalski’s horses are the flagship
species of the protected area and are highly valued
by the local people, so that negative encounters
between people and Przewalski’s horses have
been rare and Przewalski’s horses are more
tolerant to human presence than other wildlife
subject to poaching (Kaczensky 2007; Šturm
et al., 2017)”plainCitation”:”(Kaczensky 2007;
Šturm et al. 2017. Furthermore, Przwalski’s
horses are very conservative and stay mainly in
the area where they had been released and only
slowly expand their home range (Ganbaatar
2003, Kaczensky et al., 2008). Our results show
that herders prefer the wide grass pastures of
the Great Gobi B SPA to feed their livestock,
especially during spring and autumn. We recorded
Przewalski’s horse distribution mainly in the plant
community Haloxylon ammondendron, the most
characteristic shrub species of this desert-steppe
(Hilbig 1995; Wesche et al., 2005). In the Eastern
part, however, we found that Przewalski’s horses

also used the same grass pasture as livestock. Our
observations are in line with the findings of Šturm
et al., (2017)morphological and behavioural traits
resulting in different dietary niches. Wild equids
are a rather uniform group of large herbivores
which have dramatically declined in numbers and
range. Correlative evidence suggests that pasture
competition with livestock is one of the key
factors for this decline, and the situation may be
aggravated in areas where different equid species
overlap. The Dzungarian Gobi is currently the
only place where two wild equid species coexist
and share the range with the domesticated form
of a third equid species. In the winter-cold Gobi
desert pasture productivity is low, highly seasonal,
and wild equids additionally face increasing
livestock densities. We used stable isotope
chronologies of tail hairs to draw inferences about
multi-year diet seasonality, isotopic dietary niches
and physiological adaptations in the Asiatic wild
ass (khulan who showed that Przwalski’s horses
mainly feed on grass dominated pastures and
prefer to hide in the higher stands of Haloxylon
ammondendron. Our study was limited to
identifying range overlaps between Przewalski’s
horses and livestock. Yet, findings by Šturm et
al., (2017)morphological and behavioural traits
resulting in different dietary niches. Wild equids
are a rather uniform group of large herbivores
which have dramatically declined in numbers and
range. Correlative evidence suggests that pasture
competition with livestock is one of the key
factors for this decline, and the situation may be
aggravated in areas where different equid species
overlap. The Dzungarian Gobi is currently the
only place where two wild equid species coexist
and share the range with the domesticated form
of a third equid species. In the winter-cold Gobi
desert pasture productivity is low, highly seasonal,
and wild equids additionally face increasing
livestock densities. We used stable isotope
chronologies of tail hairs to draw inferences
about multi-year diet seasonality, isotopic dietary
niches and physiological adaptations in the
Asiatic wild ass (khulan showed diet overlaps
between Przwalski’s horses and domestic horses,
but did not look at overlap with small livestock.
The livestock herds in the Great Gobi B SPA
consist mainly of goats and sheep and especially
goats are grazing and browsing, and are thus very
likely to compete with all wild ungulate species
(Berger et al., 2013)humans have replaced large
carnivores in most areas, and human influence
not only exerts striking ecological pressures on
biodiversity at local scales but also has indirect
effects in distant corners of the world. We suggest
that the multibillion dollar cashmere industry
creates economic motivations that link western
fashion preferences for cashmere to land use in


Central Asia. This penchant for stylish clothing, in turn, encourages herders to increase livestock production which affects persistence of over 6 endangered large mammals in these remote, arid ecosystems. We hypothesized that global trade in cashmere has strong negative effects on native large mammals of deserts and grassland where cashmere-producing goats are raised. We used time series data, ecological snapshots of the biomass of native and domestic ungulates, and ecologically and behaviorally based fieldwork to test our hypothesis. In Mongolia increases in domestic goat production were associated with a 3-fold increase in local profits for herders coexisting with endangered saiga (Saiga tatarica). Considering the overlap in space and pasture use between sheep and goat flocks identified in this study, we strongly suggest that more research is needed to identify to what extent Przewalski’s horses and livestock are competing for resources in the Great Gobi B SPA. We also suggest that both herder and ungulate movement patterns are considered when identifying new zones inside the Great Gobi B SPA, so that the zonation meets the needs of traditional nomadic pastoralists and threatened wildlife which have coexisted in the Great Gobi B SPA ecosystem until now.

Acknowledgements
We thank the people who were part of this study as participants, translators or field assistants. Especially, we thank the rangers of the Great Gobi B SPA for monitoring the Przewalski’s horses and sharing their valuable knowledge with us. We are very thankful to the local herders who participated in the study and allowed us to track the movements of their herds. The first author (L.M.M.) was financially supported through a scholarship by the Heinrich Boell foundation and received research funds by the International Takhi Group (ITG). The second author (P.K.) was supported by the Research Council of Norway grant 251112.

References
Kaczensky, P., Walzer, C. and Steinhauer-Burkart, B. 2004. The Dzungarian Gobi Great Gobi Strictly Protected Area-Part B-The Dzungarian Gobi Great Gobi Strictly Protected Area -Part B-.


Where is the livestock future – plate- or land-based? The potential of knowledge-based, holistic grazing concepts for altering grazing livestock systems

Juliane Horn1, Johannes Isselstein1,2

1Grassland Science, Department for Crop Sciences, University of Goettingen, Von-Siebold-Str. 8, 37075 Goettingen, Germany
2Centre of Biodiversity and Sustainable Land Use, University of Goettingen, Büsgenweg 1, 37077 Goettingen, Germany

Keywords: livestock systems, precise spatiotemporal pasture management, precision farming, holistic framework

Abstract
In those days, livestock production heavily depended on feed grown on arable land. Pork production needs more arable land to gain one kilogram of human-edible protein, followed by chicken, beef and dairy production. In many European countries there is a sharp decline in livestock grazing. Many dairy farms are under pressure to maximize the total annual milk output per cow resulting in increased herd sizes by occupying a minimum of land and feeding of conserved forage of silage and concentrates. Such practices reinforce the competition for arable land for animal feeding as well as grassland intensification by heavily fertilization and frequent cutting to feed the non-grazing cows. This intensification results in unfavourable changes in species composition, loss of biodiversity and important ecosystem services. Moreover, development and widespread adoption of precision farming technologies for grazing systems has been stagnated for many years. The shift towards well-balanced, sustainable grazing systems, that produces more and impacts less, is not easily feasible. Indeed, achieving such grazing systems implies several scientific, technical and socio-economic challenges. These challenges need to be solved in a holistic way in order to facilitate systems integration and transformation into practise. Moreover, the transition requires disruptive innovations for improved pasture utilization by precisely timed grazing pressure for optimizing plant recovery, reducing emissions and maintaining or even recreating structural, biological and functional richness. Thus, an integrated framework combing innovative technologies and concepts is required. The inter-disciplinary project GreenGrass focuses on the development of innovative grazing systems by using novel technologies such as virtual fences and remote sensing in order to bring cows back to pasture and to use the grasslands potential in an efficient and sustainable manner.

Introduction
These days, we are confronted with an immense and emotionally charged plate debate. In recent decades, the keeping of monogastric species (pork, poultry) has obviously overtaken the role of ruminants (cattle, sheep). The global demand sharply increased over the last thirty years and is projected to increase further to the end of this decade, highest for poultry and pork. (OECD/FAO, 2020). Livestock systems negatively act on environmental processes and services by competing for land use with arable land, by greenhouse gas emissions, and by increasing the risk for further intensification and homogenization. The continuous intensification of agricultural systems led to considerable losses in species richness (Gossner et al., 2016) and ecosystem services (Allan et al., 2015). The sharp increase in poultry and pork production is most concerning as they mainly depend on feed grown on arable land as their ability to utilize nutrients from roughages is limited (Martens et al., 2012). However, also dairy cow systems are largely detached from grazing land. Today, feed intake of dairy cows heavily depends on silage and concentrated feed (Schingoethe 2017) from intensively managed pasture and arable land. To counteract the dependence on arable crops and to exploit grasslands’ potential, we recommend bringing cows back to pastures in a sustainable manner.

For sustainable grazing systems and harmonization of trade-offs in livestock productivity and ecosystem services, precision farming technologies for managing grazing animals
and delivering timely and precise information about the complex animal-plant system on the pasture are required. Although, precision farming technologies has entered the cropping industry for many years, those are still rare in managing grazing livestock. However, current advances in development of novel smart farming technologies have the potential for such precise grazing livestock management. Actually, no conceptional framework exists that adequately integrate technologies in precision livestock farming (PLF), precision grassland monitoring (Schellberg et al., 2008), information and economic evaluation and marketing concepts into a system that can be used to monitor and manage the driving factors within the grazing system and to make its outcome appropriately verified, recognized and rewarded. The shift to viable and sustainable grazing livestock systems needs a holistic, multi- and interdisciplinary framework. The project GreenGrass aims to develop a framework that assesses the potential of innovative precision sensor technologies such as virtual herding and remote sensing, information technologies, and marketing and transformation concepts for their integration into a holistic concept. Such a holistic framework needs to enable the re-connection to sustainable and viable grazing systems for the future.

Materials and methods
We evaluated scientific articles (reviews and original research) in Web of Science and databases of livestock production systems and the dairy sector to indicate the current trends. Furthermore, we searched for scientific articles for innovative precision farming technologies for pasture management. Overall, the literature research resulted in a dataset containing information of feed intake and efficiency, land-use, production and emissions for European countries and ten regions around the world, four livestock species (cattle, small ruminants, pork and poultry), and three products (milk, meat, eggs).

Results and Discussion
Pork production needs about 128 m² of arable land to gain one kilogram of human-edible protein, followed by 36 m² of arable land for chicken, 30 m² for beef production and 17 m² for dairy milk. The feed intake of pork and chicken depends mainly on maize (30% and 34%), wheat (for both 18%) and soy meal (13% for pork and 21% for chicken) all grown on arable land. Both, pork and chicken production only rely on very small amount of conserved forage. Feed grown on grassland contributes to 89 m² of grassland for beef production and 25 m² for milk production (Fig. 1). Globally, the feeding basket of the dairy cows mainly consists of roughage (67%), whereas cereals (9%), compounds (12%) and by-products such as soy meal (11%) make up a smaller feeding fraction. However, in several countries the role of pastures for cattle grazing has dramatically decreased. In those, zero-grazing and housing in tie-stalls are common for the dairy cows exceeding 50% of the dairy systems in Germany, Denmark, Italy and Spain. Whereas in Denmark, Germany and Austria fresh forage from pasture contributes only up to 7% of total feed intake, maize and grass silage complete the feeding basket up to 70% , followed by cereals, soymeal and compounds (FAO, IDF & IFCN 2014; Flachowsky et al., 2017). Grain-feeding in terms of wheat and barley and maize as well as compound feeding is generally low in e.g. New Zealand, Switzerland and the UK, but exceeds 30% of the total feed ration in e.g. Canada, Israel, Japan, Korea and South Africa. Soymeal is widely distributed within feeding systems in e.g. France, Germany, Korea and South Africa.

Perspectives for grassland management
In order to reduce the environmental risks of further expanding and intensifying the fodder production on arable land for feeding cows, sustainable grazing land-based systems with ruminants offers a good chance. Precise and efficient pasture management throughout the grazing season has the potential to largely meet the nutritional needs of cattle through fresh grass while reducing the amount of supplementary feed. To do so, the farmer needs precise spatiotemporal information on the available biomass and quality on the pasture to sufficiently feed the cows and to optimize plant recovery through precise animal distribution. However, precision farming technologies for managing grazing livestock have
been stagnated over many years. Our literature research indicates that precision technologies for measuring and improving inter- and intra-paddock efficiency of pasture systems as well as for management of grazing cows are rare. Cow management is restricted to automatic milking and walk over weighing systems, herd management software and electronic cow identification systems (Gargiulo et al., 2017; French et al., 2018). However, new technologies are getting more and more available now. Actually, advances are being made in automated technologies of virtual fencing for controlling and monitoring animal movement and behaviour and remote sensing for monitoring and evaluation of grasslands biomass and habitat structures. Concerted development, combination and integration of these two techniques embedded in a holistic framework is particularly promising. Here, the GreenGrass project started to build the holistic framework for innovative and sustainable grazing concepts for the future. Recent advances in remote sensing with constantly improving sensor technology allow the spatial distribution of habitats and plant communities as well as the biomass and quality of forage crops to be recorded in high spatial and temporal resolution (Landscape). The data flood from remote sensor is automatically processed in a multi-level information system and simulations of the agronomic and ecological outcome of different pasture management scenarios can be performed a priori (Information). So, the farmer can choose his pasture management for today. Through the virtual fencing technology the farmer implements his chosen management options from his desk by setting the virtual fences within his grazing land via satellite images on his PC or smartphone. Virtual fences control the accessibility of certain pasture areas for the grazing animals at certain times. Information about virtual fences set on the farmland is forwarded to the cow through a virtual fencing collar on her neck. Depending on the purpose of land use, the fences can be set variably; biodiversity can be maintained and promoted, and at the same time, adequate quality food can be offered in appropriate quantities. Moreover, the farmer can easily and quickly adopt his management strategy through the high flexibility for setting virtual fences (Grazing Systems). Today’s pasture utilization and habitat protection or recreation are documented via interfaces in the information systems and ensures transparency to consumers and authorities. Furthermore, marketing and pricing options for premium products and public goods are evaluated (Market). All relevant Stakeholders along the whole production chain are involved in the design and development of such an innovative grazing system facilitating its transfer into practice.

Conclusion
The grazing of ruminants is socially desirable and has a high potential to ensure the nutritional supply of animals. A knowledge-based grazing regime might be able to reduce conflicts between agricultural production and environmental protection. Modern techniques of “smart precision farming” must be used to support the development of economically and environmentally sustainable pasture systems in a multi- and interdisciplinary approach. The project GreenGrass has recently started to develop novel and sustainable pasture concepts with ruminants under the development of innovative technologies in a transformative and integrative approach and evaluation of their practical potential.

Acknowledgements
This sub-project of the joint project GreenGrass is funded by Federal Ministry of Education and Research - BMBF (Grant number: 031B0734A).

References


Diet selection by goats at Kalemando, North Darfur, Sudan

Abdelrahim I.H. Mansoor1, Babo Fadlalla2

1University of Zalingei, Faculty of Forestry Science, Department of Range Science, Zalingei – Sudan
2Sudan University of Science and Technology, College of Forestry and Range Science, Department of Range Science, Khartoum – Sudan.

Key words: Plant preference; Bite-count; Rangelands

Abstract
Pressure on rangelands of Sudan has increased in the last few decades due to increase in human population and in animal numbers. The rangelands were also impacted by climate change, desertification, agricultural expansion, mining, and overgrazing. Decreased amounts of rainfall have impoverished the natural rangelands. Goats are capable of grazing on semi-desert regions characterized by low rainfall and scarce grazing plants. It is therefore, necessary to know and enhance plant species preferred by goats to properly manage the rangelands. The present study was conducted at Kalemando, North Darfur State during the rainy season of 2017 when most plants were flowering. The aim was to investigate plant preference by goats under free grazing conditions. A range site of one km² was selected for the study. The Parker loop method was used to determine botanical composition of herbaceous plants while the point centre quarter method was used to determine density and relative density of trees and shrubs. The bite count technique was used to determine goat diet botanical composition. The herbaceous layer manifested 34 species of which 50.76% were forbs, while grasses constituted 49.24%. The dominant herbaceous plants were *Dactyloctenium aegyptium* (16.08%), *Aristida spp* (13.04%), *Zaleya Pentandra* (9.27%), *Trigonella hamosa* (8.70%), *Echinocloa colona* (6.38%) and *Aerva javonica* (5.36%). Tree and shrub of highest relative density were *Acacia tortils* (67.86%), *Boscia sengalensis* (14.29%), and *Grewia tenax* (3.57%). The diet selected by goats comprised trees/shrubs (42.17%), forbs (36.15%) and grasses (21.68%). Plants most preferred were *Commelina kotschyi*, *Justicia kotschyi*, *Tribulus terrestris*, *Trigonella hamosa*, *Echinocloa colona*, *Perminna resinosa*, *Grewia tenax*, and *Acacia mellifera*. It is concluded that rehabilitation of rangelands can best be effected by resort to plant species preferred by goats.

Introduction

Animals graze according to nutritional needs; palatability and ease of access. They choose specific plants or parts of plants if not controlled. Goats are characterized by selective grazing mainly based on the exploitation of rangeland resources which are subject to high quantitative and qualitative variations over the year. Fodder trees and shrubs are an integral part of the diet of these animals and constitute the main source of proteins, minerals and vitamins during the dry season (Dicko and Sikena 1991). Preference is defined as the relative consumption of one plant over another by a specific class of animal when given free choice at a particular time and place (Frost and Ruyle1993). Preference is defined in terms of free choice by an animal. It is essentially behavioral. Relative preference indicates proportional choice among two or more foods (Heady 1964). Goat is the dominant animal in the study area due to ease of raising and adaptation to harsh environmental conditions accompanied by inadequate quality feed. Therefore, this study aimed to identify plants preferred by goats and plant composition of rangeland.

Materials and methods

The Study area is located in the south eastern part of North Darfur State, 19 km from the State capital El Fasher. The site shows arid and semi-arid climate; hot in summer and cold in winter, the mean maximum and minimum temperatures are 34.7°C and 17.7 °C respectively. The average rainfall ranges between 75-287 mm/year and is characterized by fluctuation from one year to another. The area hosts diverse types of plants (EMS, 2017).

An area of one square kilometer in open rangeland was selected for determination of botanical
composition. The density and relative density of trees and shrubs were determined by the point centre quarter method. Botanical composition of the herbaceous layer of the rangeland was measured by the Parker loop method (Parker and Harris 1959). The bite count technique (Van Dyne, 1968) was used to determine the botanical composition of the diet selected by goats. Five goats were selected and observed for three days 09:00 am to 11:30 am, and from 4:00 pm to 6:30 pm. Each goat was observed for a total of 60 minutes/day; the number of bites made by goat on various forage species was recorded. The relative preference index (RPI) was used to classify plants according to their preference and, for herbaceous plants, it is obtained from the relationship: RPI % = Species in Diet (%) ÷ Species botanical composition in range (%). The range plants were classified according to their (RPI) into five forage value categories (NRC 2003) and (Abdelkreim 2012): PP = Preferred Plant (RPI more than 1.25), DP = Desirable Plant (RPI about 0.75 to 1.24), UP = Undesirable Plant (RPI less than 0.75), NCP = Non-consumed plants, and TP = Toxic plants.

Three line transects were selected, each was 300 m long, to measure plant species %, litter %, rock %, bare soil %, and animal pellets % at intervals of one meter using 0.75” loop. The data collected were recorded in a specified sheet. Also, along each of these line transects seven points were taken to measure density and relative density of trees and shrubs by using the point-center quarter method (Cottam and Curtis 1956) cited by David et al., (2004). In this method average distance (AD) for all sample points is calculated as: AD = summation all distance in all points ÷ number of points.

Density of all trees/shrubs (D) = area of sample plot ÷ (AD)².

Density of trees / shrubs spp = number of species ÷ number of trees in all points × density of all trees (D). Relative density = density of species ÷ all density × 100.

**Results**

Table 1 includes plant composition of the rangeland and the botanical composition of the diet selected by goats. Table 2 shows density and relative density of trees and shrubs.

**Table 1: Botanical composition of the diet selected by goats at flowering stage during seasons 2017**

<table>
<thead>
<tr>
<th>Scientific name/plant type</th>
<th>% in Range-land</th>
<th>% in Diet</th>
<th>*RPI</th>
<th>**PC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Forbs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigonella hamosa</td>
<td>8.70</td>
<td>11.20</td>
<td>1.29</td>
<td>PP</td>
</tr>
<tr>
<td>Commelina kotschyi</td>
<td>1.16</td>
<td>8.24</td>
<td>7.10</td>
<td>PP</td>
</tr>
<tr>
<td>Justicia kotschyi</td>
<td>1.89</td>
<td>3.79</td>
<td>2.01</td>
<td>PP</td>
</tr>
<tr>
<td>Tribulus terrestris</td>
<td>1.16</td>
<td>2.11</td>
<td>1.82</td>
<td>PP</td>
</tr>
<tr>
<td>Alichecarpus vaginalis</td>
<td>4.64</td>
<td>4.32</td>
<td>0.93</td>
<td>DP</td>
</tr>
<tr>
<td>Zalya pentandra</td>
<td>9.27</td>
<td>2.03</td>
<td>0.22</td>
<td>UP</td>
</tr>
<tr>
<td>Aerva javonica</td>
<td>5.36</td>
<td>0.27</td>
<td>0.05</td>
<td>UP</td>
</tr>
<tr>
<td>Mollugo noduavlis</td>
<td>3.63</td>
<td>0.98</td>
<td>0.27</td>
<td>UP</td>
</tr>
<tr>
<td>Corchorus olitorius</td>
<td>3.48</td>
<td>0.18</td>
<td>0.05</td>
<td>UP</td>
</tr>
<tr>
<td>Portulaca oleracea</td>
<td>1.59</td>
<td>0.00</td>
<td>0.00</td>
<td>NCP</td>
</tr>
<tr>
<td>Other forbs</td>
<td>9.88</td>
<td>3.03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Forbs</strong></td>
<td><strong>50.76</strong></td>
<td><strong>36.15</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B. Grasses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echinocloa colona</td>
<td>6.38</td>
<td>8.45</td>
<td>1.32</td>
<td>PP</td>
</tr>
<tr>
<td>Bracharia deflex</td>
<td>1.16</td>
<td>0.88</td>
<td>0.76</td>
<td>DP</td>
</tr>
<tr>
<td>Dactyloctenium aegyptium</td>
<td>16.08</td>
<td>8.47</td>
<td>0.53</td>
<td>UP</td>
</tr>
<tr>
<td>Cyperus rotundus</td>
<td>5.22</td>
<td>3.56</td>
<td>0.68</td>
<td>UP</td>
</tr>
<tr>
<td>Aristida spp</td>
<td>13.04</td>
<td>0.18</td>
<td>0.01</td>
<td>UP</td>
</tr>
<tr>
<td>Eragrostis diplachnoides</td>
<td>3.18</td>
<td>0.10</td>
<td>0.03</td>
<td>UP</td>
</tr>
<tr>
<td>Eragrostis tremula</td>
<td>1.73</td>
<td>0.00</td>
<td>0.00</td>
<td>NCP</td>
</tr>
<tr>
<td>Zornia diphylla</td>
<td>1.59</td>
<td>0.00</td>
<td>0.00</td>
<td>NCP</td>
</tr>
<tr>
<td>other Grass</td>
<td>0.86</td>
<td>0.04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Grass</strong></td>
<td><strong>49.24</strong></td>
<td><strong>21.68</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C. Trees/Shrubs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acacia tortilis</td>
<td>-</td>
<td>25.91</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grewia tenax</td>
<td>-</td>
<td>5.29</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
As shown in Table 1, goats grazed with high selectivity as appears from range inventory in the study area. It was found that 34 plant species out of 47 detected were selected by goats, the highest class of plants recorded was trees and shrubs (42.17%), followed by forbs (36.15%) and then grasses (21.68%). Based on percentages of browse and herbaceous species in dietary composition, goats have been described as browsers-grazer. This is in variance with the finding of Sidahmed et al. (1981) who described goats as browsers according to percentages of browse and herbaceous species in dietary composition. This may be attributed to the diversity of plants where our study was conducted. The plants most preferred were Commelina kotschyi, Justicia kotschyi, Tribulus terrestris, Trigonella hamosa, Echinocloa colona, Permina resinosa, Grewia tenax and Acacia mellifera. These plants are characterized by soft stems and abundance of leaves and twigs. Morand-Fehr et al. (1981) stated that goats select the most nutritive parts of plants such as leaves compared with stems. Some tree, grass and forb species appeared in the diet but not in the botanical composition of the range such as Acacia senegal (1.41%). This may be due to the extensive use of Acacia senegal as building materials and the use of their roots in handicraft. Moreover, some plants were found in the range but not in the diet selected by goats such as Eragrostis tremula, Zornia diphylla, Protulaca oleracea, Boerhavia erecta and Boscia sengalensis. This is consistent with (Adam et al. 2012) who reported that Eragrostis tremula and Zornia diphylla were non consumed by goats in high growth stage. Plants that dominated the range site were Dactyloctenium aegyptium (16.08%), Aristida spp (13.04%), Zaleya Pentandra (9.27%) and Trigonella hamosa (8.70%).

As described in Table (2) it is concluded that trees and shrubs were sparsely distributed in the range site according to mean distance (52.43m) for all points sampled in the plot, (trees density was 364 trees/shrubs /km²). Some trees that formed a high percentage in relative density such as Acacia tortils, Boscia sengalensis, and Grewia tenax (67.86%, 14.29% and 3.57% respectively) are classified as dominant species in the range site. Boscia sengalensis is ecologically the most important species showing good regeneration and high tolerance to fire (IBGR 1984). Factors such as population increase and ensuing anthropogenic activities such as tree felling for use in building, firewood and charcoal, overgrazing, early grazing and drought negatively impacted the range (Mansoor 2015). There is a decline in vegetation cover, especially trees and shrubs. Therefore, care must be taken to change the range management methods to match the sustainability of rangeland resources. Goats selected more trees than forbs or grasses in their diet. It is concluded that rangelands

Table 2: Trees/shrubs density and relative density in study area

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Tree / shrub density (Plant/km²)</th>
<th>Trees/shrubs relative density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia tortils</td>
<td>247</td>
<td>67.00</td>
</tr>
<tr>
<td>Boscia sengalensis</td>
<td>52</td>
<td>14.29</td>
</tr>
<tr>
<td>Acacia nilotica</td>
<td>4</td>
<td>1.10</td>
</tr>
<tr>
<td>Maerua crassifolia</td>
<td>9</td>
<td>2.47</td>
</tr>
<tr>
<td>Leptadenia pyrotechnica</td>
<td>4</td>
<td>1.10</td>
</tr>
<tr>
<td>Permina resinosa</td>
<td>9</td>
<td>2.47</td>
</tr>
<tr>
<td>Acacia mellifera</td>
<td>9</td>
<td>2.47</td>
</tr>
<tr>
<td>Ziziphus spina Christi</td>
<td>4</td>
<td>1.10</td>
</tr>
<tr>
<td>Balanites aegyptiaca</td>
<td>9</td>
<td>2.47</td>
</tr>
<tr>
<td>Capparis deciduas</td>
<td>4</td>
<td>1.10</td>
</tr>
<tr>
<td>Grewia tenax</td>
<td>13</td>
<td>3.57</td>
</tr>
<tr>
<td>Total</td>
<td>364</td>
<td>100.00</td>
</tr>
</tbody>
</table>
rehabilitation should take into account plants species that are preferred by goats.

**Acknowledgements**

We extend our thanks and appreciation to pastoralists households who allowed us to use their animals for the experiment.

---

**References**


Choosy grazers and plant communities – Interactions between cattle breeds and vegetation in semi-natural pastures

Pauler C.M.1,2,3; Isselstein J.2; Berard J.1,4; Braunbeck T.3; Schneider M.K.1

1 Forage Production and Grassland Systems, Agroscope, 8046 Zurich, Switzerland; 2 Department of Crop Sciences, Georg-August-University, 37075 Goettingen, Germany; 3 Centre for Organismal Studies, Ruprecht-Karls-University, 69120 Heidelberg, Germany; 4 AgroVet-Strickhof, 8315 Lindau, Switzerland;

Key words: cattle breeds; plant diversity; forage selection; trampling impact

Abstract

It is well recognized that domesticated and wild ruminant grazers have an important impact on the composition of grassland vegetation, mainly by forage selection, trampling and defaecation. However, little is known on the effects of genetic diversity, for example differences among breeds of cattle. Cattle breeds differ in terms of robustness, growth rate, weight and probably also in movement and forage selection behaviour, which all could impact vegetation composition. Our study therefore aimed at identifying breed-specific differences in forage selection and behaviour and its consequences for vegetation. In a controlled experiment on semi-natural pastures in the Swiss Alps, suckler cows of three cattle breeds (high-yielding Angus’Holstein crossbreeds, dual-purpose Original Braunvieh and slow-growing Highland cattle) grazed a series of adjacent paddocks. Plant species selection of the cattle was quantified by assessing biomass proportions of all plant species in vegetation subplots before and after pasturing. Movement behaviour was monitored using GPS sensors and pedometers. To assess long-term effects of cattle breeds on vegetation, we recorded vegetation composition in 50 paired pastures in mountain areas of Switzerland and in southern Germany, which were either grazed by Highland cattle or a production-oriented cattle breed. Low-productive Highland cattle selected plant species less strictly than the two higher-yielding breeds. They also exerted less physical pressure on the vegetation, because they were substantially lighter, but had relatively large claws. Highland cattle moved less actively, likely because of less selective foraging. These differences showed a strong correlation with differences in pasture vegetation, namely a smaller number of indicator plants for grazing and trampling tolerance on pastures of Highland cattle. Moreover, plant species richness was significantly increased by pasturing with Highland cattle, suggesting a high potential of robust breeds for sustaining or even increasing the diversity of species-rich pastures.

Introduction

The species richness of semi-natural pastures in European mountain areas, formed by grazing livestock over centuries, is endangered by structural changes in agriculture: Mountain farms have changed from subsistence smallholder farming to professional, specialised dairy or meat producers. Increased mobility and diverse job opportunities strongly reduced the number of employees in agriculture. At the same time, human artificial selection formed cattle breeds with increased milk or meat production and these high-productive breeds account for a majority of cattle today. However, elevated productivity came along with increased requirements, for example high nutritive demands. As a consequence of these agricultural changes, high-productive cattle are reared on the agriculturally best pastures, whereas nutrient-poor, marginal grasslands are underused. Both intensification and abandonment reduce the biodiversity of marginal pastures (Peter et al., 2009; Strebel and Bühler, 2015; Zehnder et al., 2020). However, besides high-productive modern cattle, there are traditional breeds almost untouched by output-oriented breeding and, thus, less productive and less demanding. Apart from breeding aims easy to quantify, such as milk and meat yield, little attention was paid to breed characteristics which possibly co-evolved unnoticed during the breeding process, such as anatomy, movement and foraging behaviour. Such unnoticed traits could have a lasting effect on plant species composition of pasture vegetation as they could modify the specific interaction of grazers and vegetation.
We therefore aimed at estimating differences between low- and high-productive cattle breeds, quantifying their long-term impact on pasture vegetation and analysing their suitability for the maintenance of species-rich, marginal grasslands by combining two scientific approaches: (1) a controlled grazing experiment and (2) an observational field study.

Methods and Study Site
In a controlled grazing experiment, we investigated three cattle breeds, representing different levels of productivity: (i) low-productive Highland cattle, (ii) traditional, dual-purpose Original Braunvieh and (iii) high-productive Angus×Holstein crossbreed (Pauler et al., 2020a, 2020b). The cattle simultaneously grazed three types of heterogenous subalpine pastures in the Swiss Alps (2026 m asl.) in a Latin-square design. Individual body weight and claw base area of nine cows per breed were measured. To analyse movement behaviour, we recorded movement intensity and space use evenness using GPS tracking and pedometers. In addition, we visually observed foraging behaviour by recording plant consumption at species level during foraging and changes in plant species' biomass proportions before and after grazing. Finally, we calculated the forage preference for different plant species and plant traits (Kattge et al., 2020), the quality of the diet selected (Briemle et al., 2002) by each cow using indicator values as well as the evenness of forage selection (Pielou index) and space use (Camargo index).

To analyse the long-term effect of grazing with high- or low-productive breeds, we conducted an observational vegetation study along a broad environmental gradient from Southern Germany to the Swiss Alps (Pauler et al., 2019) slower-growing and less demanding on forage than most production-oriented cattle breeds, which may affect vegetation composition. This study aimed at identifying the importance of breed-dependent impact on the composition of pasture vegetation in comparison to well-investigated factors such as site properties and grazing management. Vegetation was investigated in 50 paired pastures at 25 locations ranging from Swiss mountain areas to lowlands in southern Germany. Pastures in a pair had been grazed by either Highland cattle or a more production-oriented cattle breed for at least 5 years. Plant species composition was assessed on 150 subplots, three per pasture in areas representing different grazing intensities. Generalized linear mixed-effects models, (partial. Thereby, we examined the vegetation composition of highly comparable paired pastures, either grazed low-productive Highland cattle or high-productive breeds for at least five years.

Results and Discussion
Breeds differ in weight, claw size and movement behaviour
There were consistent differences among breeds in anatomy, movement and foraging behaviour (Figures 1 and 2). Especially Highland cattle significantly differed from the two more productive breeds, whereas there was only little divergence between Original Braunvieh and Angus×Holstein cattle (Pauler et al., 2020a).

Highland cattle were significantly lighter than the other two breeds (Figure 1a). On average, Highland cattle weight 358 kg, Original Braunvieh 582 kg and Angus×Holstein 679 kg. Claw base was also smaller in Highland cattle (Figure 1b); yet, it was relatively large normalized to body weight: On each square centimetre claw base of a Highland cow burdened about one third less body weight than of an Angus×Holstein cow (Figure 1c). The light body weight on relatively large claws of Highland cattle reduces physical pressure to the vegetation. Moreover, GPS and pedometers indicated that Highland cattle moved least (Figure 1d); yet, it was relatively large normalized to body weight. On each square centimetre claw base of a Highland cow burdened about one third less body weight than of an Angus×Holstein cow (Figure 1c). The light body weight on relatively large claws of Highland cattle reduces physical pressure to the vegetation. Moreover, GPS and pedometers indicated that Highland cattle moved least (Figure 1d), but used the space and the available forage plants most evenly (Figures. 1e and f).

Figure 1: Differences of three cattle breeds in pasture-relevant traits: a) body weight in kg, b) base area of all four claws in cm², c) pressure burdening the ground in kg/cm², d) movement intensity in steps per hour, e) evenness of space use calculated as Camargo Index, and g) the evenness of forage.
selection as Pielou index. Except for movement intensity (6 cows per breed), data are given for 9 cows per breed. Boxes represent the interquartile range covering half the values.

**Breeds differ in forage selection**

A closer look on selection evenness reveals that low-productive Highland cattle not only select the forage plant *species* less strictly, but that their choice depends less on forage quality and other plant traits (Figure 2; Pauler *et al.*, 2020b): Among the three breeds, highland cattle chose the diet of lowest quality. The less productive a breed was, the lower the quality of the selected forage (Figure 2a). Highland cattle consumed nutrient-poor plant species more frequently than the more productive breeds (Figure 2b). Moreover, they cared less about the specific leaf area (i.e. a measure of digestibility; Figure 2c) and avoided shrubs (Figure 2d) and other unattractive plants least. On the contrary, Original Braunvieh and Angus×Holstein foraged more broad-leaved grasses and legumes. Most importantly, however, Highland cattle were the only breed gaining weight on the low-quality forage of the alpine pastures in the study area, suggesting lower energy demands (less movement, warmer fur) and a more efficient conversion of fibre-rich fodder.

**Figure 2:** Impact of plant traits on the forage selection by three cattle breeds. Boxes indicate the average response of cattle breed’s forage decision to the four traits a) forage quality, b) nitrogen content, c) specific leaf area and d) woodiness: Strong (++) or moderate (+) preference, if trait value is elevated; strong (--) or moderate (-) avoidance, if trait value is lower. The central zero-line indicates no influence of a plant trait on forage decision. Analysed were the biomass proportion of all plant species within 165 vegetation sub-plots (3×3 m) before and after grazing by the three cattle breeds.

**Vegetation adapts to differences among breeds**

In long-term, pasture vegetation adapts do breed-specific competitive conditions (Figure 3). Light and broad-footed Highland cattle exert less pressure to the ground. Consequently, there were significantly less trampling-adapted plant species on pastures of Highland cattle. On the pastures of high-productive, heavy breeds, these were more frequent because of a higher competitive advantage (Figure 3a). Moreover, since Highland cattle were least choosy while foraging, they needed to walk shortest distances, as they just fed on what was in close proximity of their mouth. Thereby, they additionally reduced trampling pressure.

Likewise, differences in forage selection among breeds have a long-term impact on pasture vegetation. The vegetation of pastures grazed over a long period by high-productive breeds showed significantly higher grazing-indicator values than vegetation grazed by Highland cattle (Figure 3b). Plants adapted to defoliation (e.g. by low forage quality, low specific leaf area, woodiness) were found more frequently on the pastures of high-productive and high-selective cattle. Grazing-adapted plant species benefit from the strict selectivity of high-productive breeds and become dominant.

**Figure 3:** Differences in vegetation between pastures grazed by Highland cattle and adjacent pastures of high-productive cattle breeds. Analysed were 25 pasture pairs grazed for at least 5 years by the respective breed. The two pastures of a pair were comparable in terms of management and site conditions. On each pasture, the percentage cover of all plant species was estimated in 3 sub-plots (5×5 m). The cover-
weighted mean of a) grazing indicator value and b) trampling indicator value (Briemle et al., 2002) was calculated and c) the number of plant species counted.

**Low-productive cattle enhance species-richness**

Moreover, the high trampling pressure and selectivity of high-productive breeds decreased plant species richness on pastures (Figure 3 c; Pauler et al., 2019) slower-growing and less demanding on forage than most production-oriented cattle breeds, which may affect vegetation composition. This study aimed at identifying the importance of breed-dependent impact on the composition of pasture vegetation in comparison to well-investigated factors such as site properties and grazing management. Vegetation was investigated in 50 paired pastures at 25 locations ranging from Swiss mountain areas to lowlands in southern Germany. Pastures in a pair had been grazed by either Highland cattle or a more production-oriented cattle breed for at least 5 years. Plant species composition was assessed on 150 subplots, three per pasture in areas representing different grazing intensities. Generalized linear mixed-effects models, (partial, because species well adapted to trampling or grazing outcompete less resistant plants. Consequently, the species richness was lower on pastures of high-productive cattle breeds. The longer the pastures of a pair had already been grazed by the respective breeds, the clearer was the contrast. Additionally, vegetation grazed over extended periods by low-productive Highland cattle had a higher share of epizochoric and a lower abundance of woody species. Both contributed positively to plant species richness.

**Conclusions**

Besides desired characteristics, modern breeding unintentionally changed hidden traits of cattle anatomy, movement and foraging behaviour. Thereby, breeding modified not only the cattle themselves, but also the vegetation grazed by these animals. The differences found in the vegetation grazed by either low- or high-productive cattle can consistently be explained by the differences in cattle traits.

Today, semi-natural low-input pastures are endangered, but low-productive cattle contribute to maintain or even promote the biodiversity of these habitats. Low-productive breeds can be a worthwhile addition to more intensive livestock, e.g., for using and managing ecologically valuable land. However, desirable traits of low-productive cattle breeds may be lost when breeding is geared towards higher output. It is thus recommended to preserve their low productivity as a specific trait.

**Acknowledgements**

The authors are grateful to all the farmers who made this study possible, as well as to the Studienstiftung des deutschen Volkes and the Fondation Sur-la-Croix for financial support.

**References**


THEME 4: WILDLIFE, TOURISM AND MULTI-FACETS OF RANGELAND/GRASSLAND

Topic: A Revolution in Conservation Innovation By and With Pastoralists: Examples From Kenya, Africa and the Globe
Conservation Innovation in Pastoral Lands around the Globe: Challenges, Lessons and Opportunities

Reid, R.S., Colorado State University, Fort Collins, Colorado, USA

Key words: Collaborative conservation; open access; devolution

Abstract
Pastoralists and ranchers have a long history of sustained management of rangelands around the world. Several decades ago, some pastoralists and ranchers started new alliances with environmental organizations, businesses and government agencies to diversify their approaches to land management to include what can be called ‘conservation’. These efforts highlight conserving aspects of rangeland ecosystems, but often have an equal or greater emphasis on supporting pastoral livelihoods and culture. This paper asks: What types of innovations are pastoralists now pursuing in ‘conservation’? How are these innovations performing?

This paper provides a synthesis of some of the types of conservation innovations being led by pastoralists and ranchers around the world. In rangelands that are privately owned, much of the innovation focuses on management practices, like rangeland restoration, regenerative ranching, education, and herding strategies. But some private landowners are taking down fences or herding animals across pastures. In the majority of the world’s rangelands, which are commonly managed, conservation innovations emphasize new locally-led governance regimes and institutional innovations. These often build upon and strengthen traditional pastoral management practices and institutions. The most impactful conservation innovations, in the face of urban spread and development, may be those that either maintain the ability of pastoralists and ranchers to keep the land open or allow them to un-fragment fragmented land and knit it back together. Unfortunately, social and ecological outcomes of conservation efforts are rarely assessed over the long term, so it is unclear how impactful these innovations are. Continuing challenges in these initiatives include how to ensure all pastoralists and ranchers benefit (resource-limited pastoralists, women, youth), how to adapt given accelerating climate change, and how conservation innovations can increase the bottom line of ranchers.

Introduction
Pastoral peoples and rangelands now face accelerating economic, political and climatic change that often reduce their joint resilience and capacity to respond to change (Reid, Fernández-Giménez, and Galvin 2014). Pastoralists, however, are often masters of innovation and adaptation, given that they survive and often thrive under harsh and unpredictable conditions. Several decades ago, some pastoralists and ranchers started new alliances with environmental organizations, businesses and government agencies to diversify their approaches to land management to include what can be called ‘conservation’ (McDonald 2002). These alliances occur all over the world, ranging from those on common land in Africa and Asia, to those on private ranches in Australia and North America (Reid, Fernández-Giménez, and Galvin 2014). Because of the leadership or strong partnership of pastoralists in these alliances, most are not just about conservation but emphasize pastoral livelihoods and culture. This paper asks: What types of innovations are pastoralists pursuing in ‘conservation’? How are these innovations performing? Given its brevity, this paper is far from comprehensive, but is rather an initial exploration of new progress in pastoral conservation.

Methods and Study Site
This is a review of current and future possible innovations in conservation in pastoral lands. It is a traditional not systematic review; I read recent future-oriented papers and websites, creating the idiiosyncratic synthesis of patterns described here.

Results and Discussion
One of the reasons many pastoralists and conservationists are working closely together is a major shift in how we think and talk about pastoralism. Old myths about the tragedy of
the commons or the idea that livestock always overgraze are falling away. New ideas that pastoralism is one of the most compatible land uses with conservation have started to take their place. Because of this shift, pastoralists themselves are becoming recognized as leading conservationists.

Of the many conservation innovations in pastoral lands, I focus on four main major types of innovations. The first are innovations that create the win-win of keeping land open for both conservation and pastoralism. This openness not only helps livestock and wildlife but conserves plant species and important habitats that are part of rangelands. In the face of rapidly changing land use, this is critical to allowing both pastoralism and conservation to succeed. Innovations here include strong efforts by private land owners to welcome wildlife on their lands with livestock, which, in southern Africa, for example, doubles the amount of land conserving wildlife compared with that in parks and reserves (Kreuter, Peel, and Warner 2010). Key in these private lands initiatives is the ability of landowners to find new funding streams with wildlife that help compensate for the disease and predator costs of mixing livestock with wildlife. On pastoral lands used in common, which dominate global rangelands, community-based rangeland management (CBRM) creates formal and informal decision making bodies and institutions that not only keep land open, but sometimes push back on new land uses brought in by outsiders (Hobbs, Bernández-Giménez, and Galvin 2014). Sometimes governments establish conservation areas that are multiple use, likely the Ngorongoro Conservation Area in Tanzania, realizing that pastoralism and wildlife are more compatible than mixing wildlife with uses like mining and crop farming.

Another related innovation is knitting land back together that has been fragmented by privatization of common land. Here, pastoralists are participating in and leading collaborative conservation initiatives that ‘soften’ the boundaries created by fencing on private land. Sometimes this means removing fences or cultivated plots (or even roads in the future). Other efforts establish agreements among pastoralists to graze land on multiple parcels together or move herds opportunistically to share forage among neighbors (Hobbs et al., 2008). For all of these types of initiatives, the biggest impact often comes from the trust built when people from opposing viewpoints come together and agree to collaborate over the long term (Hillis et al., 2020).

A third set of innovations focuses on true devolution of power to pastoral communities so that they design and lead joint pastoralism / conservation efforts on their traditional common land. Efforts to devolve power sometimes have limited success in the face of governmental reluctance to share decision making power over common land (Reid, Jablonski, and Pickering 2021). More common are ‘hybrid institutions’ that do not require full devolution, but rather blend the decision making power of pastoralists, NGOs and government in joint decision-making bodies (Robinson et al., 2018). In Ethiopia, for example, there are substantial efforts to strengthen and support pastoral customary institutions of grazing management, which sometimes are pastoral led, but more often create these hybrid institutions (Flintan et al., 2019). In Kenya, community conservancies are hybrid institutions, with pastoralists, government and NGOs managing wildlife and pastoralism together (KWCA 2016).

But there are a few, new examples of pastoralist-designed and led conservation initiatives, like Nashulai Conservancy in the Mara of southwest Kenya. Here, Maasai pastoralists are completely in charge of all decision making. In doing so, the Nashulai community developed a linked model of ‘conserve wildlife – preserve culture – reverse poverty’ with a unique focus on empowerment of women (Nashulai 2021). They established a bird sanctuary and elephant nursery; rehabilitated grasslands by reestablishing seasonal and rotational grazing with fewer, higher quality Boran cattle; restored and monitored water quality in a nearby river; established a formal governing conservancy; and founded the Mara Cultural Training Institute to link pastoralism, culture and wildlife. This level of innovation is also exemplified by the new Narentunoi Conservancy near Nairobi (Parmisa and Reid This volume).

Another innovation is the return of land to Indigenous Peoples in countries where settler colonial powers stole indigenous land. Sometimes this is a trade-off for pastoralism because many Indigenous People do not herd livestock (and many do) and thus pastoralism may decline when land is returned. Examples include the transfer of city or state or federal land to Native Nations in the US (Various1 2021). Private landowners sometime bequeath land back to the indigenous owners. This return of land appears to be a trickle compared to the rushing currents in the opposite direction where non-Indigenous people grab even more indigenous land (Borras and Franco 2012; Abbink 2011). This land grabbing continues, even to create parks and reserves, despite mounting evidence that indigenous management is often superior to management of the parks by settler colonial governments (Sangha 2020).

Fourth, pastoralists have long practiced innovative
grazing and conservation practices with current restoration of traditional practices and adoption of new ones. Despite a long controversy on the scientific value of rotational grazing, many ranchers and pastoralists see improvement of their grazing lands with this approach (Nashulai 2021; Gosnell, Charnley, and Stanley 2020). Another new development is the realization that “modern” ranching on private land has something to learn from pastoralism on common land. This is new because there has long been the assumption that private lands ranching is more productive than common lands pastoralism, but this has been challenged (Behnke 2008). African pastoralists, for example, have long exploited diverse and varying landscapes and grassland types to ensure herd productivity and stability. This exploitation of heterogeneity is now recognized as a key strategy for pastoralists and ranchers worldwide (Briske et al., 2020).

What innovations support these pastoral conservation initiatives? One of the most important is educational opportunities for pastoralists that support and respect pastoral knowledge and empower their leadership of these initiatives (Coppock et al., 2017). On the research side, there has been an evolution of the level of participation of pastoralists in research, from research subject to research participant to research leader (Reid et al., 2016). There is also a great deal of innovation in the types of partnerships that pastoralists make with researchers. In Colorado of the US, for example, ranchers and researchers now work hand-in-hand on a 10-year experiment comparing continuous grazing with adaptive management (Fernández-Giménez et al., 2019). Both education and research can create transformative opportunities for social learning for individuals or whole communities (Reid et al., 2021).

Discussion and Implications
How are these innovations performing? In most cases, we have little evidence or the evidence is mixed. The impacts of community-based conservation, for example, shows they can successfully achieve either social or ecological outcomes, but win-wins of these two types of outcomes are more rare (Brooks, Waylen, and Mulder 2013; Galvin, Beeton and Luizza 2018). Continuing challenges in these initiatives include how to ensure all pastoralists and ranchers benefit (resource-limited pastoralists, women, youth), how to adapt given accelerating climate change, and how conservation innovations can increase the bottom line of pastoralists.

And what are some ideas for pastoralists and ranchers to consider for the future? Following in the footsteps of the Maori people of Aotearoa/New Zealand, pastoralists may want to consider the value of granting ‘personhood’ to parts of pastoral lands (Muller, Hemming, and Rigney 2019). In the Maori case, the colonial government recognized the rights of the Whanganui River, thus protecting it more strongly from a proposed dam. In the case of pastoralists, personhood or nature’s rights might help pastoralists push back on governmental or corporate land grabbing or powerful extractive industries like mining.

There is also new thinking that open access grazing systems, in very dry, non-equilibrial pastoral systems, need governance structures entirely different than those on wetter, common property land (Moritz et al., 2018). This may mean that some of the driest lands are suited to the relative ‘free-for-all’ that started the idea of tragedy of the commons in the first place. This means conservation will be different in these very dry systems also. This idea also highlights the importance of strong governance structures in wetter, more equilibrial rangelands where overuse is clearly possible.

In conclusion, it is likely that one of the most lasting innovations will be as pastoralists come to ‘own’ conservation action on their own lands. This has the prospect of shifting conservation from an idea imposed from the outside by environmentalists to an entirely new venture, aligned with pastoral culture and livelihoods.

Acknowledgements
My greatest teachers have always been indigenous pastoralists around the world. Many conservation practitioners and scholars also broadened my thinking. I thank the International Livestock Research Institute and the Dept of Ecosystem Science and Sustainability and the Center for Collaborative Conservation at Colorado State University for moral and financial support during my learning journey.
References


Social-Ecological Innovations and Outcomes of Community-Based Conservation in Africa: Implications for the Future

Galvin, K.A.

Department of Anthropology and Geography, Colorado State University

Abstract
Community-based conservancies (CBCs) are growing in numbers throughout Africa, particularly in the arid and semi-arid (ASAL) regions where pastoralists raise livestock and live among much of Africa’s remaining wildlife. CBCs emerge around national parks and other protected areas of wildlife spaces apart from people. Community conservancies, in contrast to national parks, are land tenure and land use governance arrangements to conserve wildlife while providing for the livelihoods of African pastoralists. Some conservancies develop by communities in partnership with public agencies, while others are associated with non-government organizations and/or the private sector. Others are more top-down in origin, supported by large international donors and governments. Conservancies tend to develop in nation states that, until recently, have ignored the ASALs. Currently however, ASALs are converting to towns and croplands as human populations and consumption grow. Shifting market incentives encourage different livestock strategies away from local production to commercial livestock products. Energy extraction and renewable energy production are expanding into these areas, transforming landscapes, communities, and rural cultures. Formerly communal rangelands are increasingly privatizing and subdividing as pastoralists permanently settle. Fragmentation of communal lands is the result. We assess the goals of formation of community-based conservation, the partnerships, and outcomes for pastoralists.

Introduction: Transformational Adaptation and CBC
Transformational adaptations in relation to climate change or other big changes are actions taken to achieve a certain goal through a combination of technological innovations, institutional reforms, behavioral shifts including gender roles, production patterns and cultural changes in values and worldviews (O’Brien 2012). Transformations can be carried out across multiple scales and dimensions, and they challenge entrenched systems and the powerful interests that maintain them (O’Brien 2012, Pelling 2015). Community based conservation (CBC) can then be considered a transformational adaptation to the myriad forces affecting the rangelands Africa. Community based conservation institutions deal with natural resource issues (e.g., maintain biological diversity) and human well-being (e.g., livelihoods), seeking to achieve the dual objectives of ecological conservation and improved rural livelihoods by offering incentives to sustainably manage natural resources and having some measure of devolution of resource management responsibilities (Berkes 2007, Suich 2010). They tend to function well when nested, flexible and contingent (Berkes 2007) to deal with changing circumstances such as extreme climatic events, policy and economic disruptions and demographic changes. CBC is inherently multilevel: including individual actors, endogenous government institutions within communities, multi-community bodies structured by interventions, states, multilateral organizations. These are some of the attributes of a successful CBC institution.

Materials and Methods
Study Site
We did a systematic search for sub-Saharan Africa of refereed articles in English and some grey literature using Web of Science and Google Scholar (n=47,000+) for terms as community-based conservancies, integrated conservation, and development, etc. We screened title and abstract of 111 papers for fit with CBC definition and whether they measured social or ecological outcomes, among other criteria. There were several tiers of analysis. Spatial analyses were completed with 73 case studies, social outcomes (n=45), ecological outcomes (n=16) and conditions affecting outcomes (n=54) (Galvin et al., 2018).
We developed a conceptual model that we used to evaluate the institutional processes and social and ecological outcomes. We assessed the institutional processes (leadership, bridging/boundary organizations, diverse and multiple partnership, collaboration, social learning, devolution of rights, monetary or non-monetary incentives) thought to lead to successful outcomes.

Social outcomes can be measured by assessing the asset or capital stock held by individuals and households (Table 1) whereas ecological outcomes are measured by the factors in Table 2. These institutional processes and outcomes explained here serve as the codes and concepts that frame the textual analysis.

Table 1. Measures for social outcomes

Results

Less than half of CBC institutions produced positive outcomes. Most cases focused on social outcomes using qualitative methods. Ecological outcomes were largely positive. Monetary and non-monetary incentives are necessary but not sufficient for positive outcomes (Figure 1). Devolution of rights to the local community was significantly associated with positive outcomes.

Discussion

Community-based conservation institutions, in general, have not consistently produced positive outcomes in Africa. More often than not the establishment of CBCs in Africa has led to negative or a mixture of positive and negative social outcomes, whereas ecological outcomes have been largely positive. Most positive social outcomes reported enhanced financial capital and human capital, while negative social outcomes reported an unequal distribution of benefits to CBC households due to elite capture at the local and broader level, and a breakdown of social capital. But there are few systematic studies and evaluation and monitoring of CBC performance is lacking. This review was only a start. CBC institutions are extremely numerous in structure, function, and goals. Further, they are difficult to start and maintain. But despite the lack of ‘success’ shown in the review they are an innovative,
Are CBC institutions a form of transformational adaptation? Despite the shortcomings it seems that it represents a collectively organized adaptation strategy planned and implemented to address the numerous external changes pressing on dryland pastoral systems. It represents, in principle, a ‘new’ institution associated with large vulnerabilities real or anticipated to conservation-development. Since adaptation produces tradeoffs with winners and losers and unintended consequences, more work is needed on the tradeoffs and the potential for vulnerability redistribution beyond CBC initiatives themselves. Further, more work on the barriers such as policies, behavioral norms and equity issues to implementation of CBC can demonstrate the risks associated with CBC institutions. Nevertheless, as an innovative transformational adaptation it is an effort to cope with the uncertainties of climate change risks and the other social/economic/policy changes occurring today.

Acknowledgements
This paper would never have materialized without the work of my co-authors Matthew Luizza and Tyler Beeton. You are rock stars. Thank you.

References


Wildlife Conservation Innovations in a Rangeland under Rapid Change in Maasailand of Kenya

Parmisa, N.\textsuperscript{1} and Reid, R.S.\textsuperscript{2}

\textsuperscript{1}Government of Kenya, Kitengela, Kenya
\textsuperscript{2}Colorado State University, Fort Collins, Colorado, USA

**Key words:** Lion lights; human wildlife conflict; conservancy

**Abstract**
Conservation efforts have often been designed without the benefit of the long-term, local knowledge held by pastoral people about rangelands and wildlife. Here, we present a case study of a rapidly changing pastoral landscape in Maasailand of Kenya, just south of Nairobi National Park. We will focus on pastoral innovations that both support pastoral livestock production and conserve wildlife at the same time, through biodiversity payment schemes (through land leasing), education, policy and appropriate technology.

The community described here established a land leasing program in 2000, to pay pastoral land owners to keep fences down and remove poaching snares to support migrating wildlife. This program has been a major success, but struggled to maintain payments to many community members over many years. Recently, the community established a wildlife education center, which provides a sustainable source of income to support the leasing program. Center staff have training programs for student research, local education on conservation and women’s beadwork.

Another big threat to livestock is predator attack. This community has widely adopted an innovation of solar powered “lion lights”, invented by one of pastoral youths from the community. These lights consist of small LEDs that surround livestock enclosures, which turn on automatically at night, thus deterring predators and reducing attacks significantly. The new Wildlife Act (2013), which our community advised on, also provides much higher compensation for injury and death of livestock.

At a broader scale, our community has been at the forefront of promoting Kenya’s first land-use master plan for a rangeland. We support this effort because we have seen waves of urban people buying pastoral land and developing properties. Our new land-use plan and government incentives give us hope that our pastoral land will remain open for livestock and wildlife in the future. Recently we strengthened these initiatives by establishing the Narentunoi Conservancy, which is recognized as a legal entity by the Kenyan government.

**Introduction**

Around the world, pastoralists and their supporters are creating new ways to manage land through community-based initiatives on their common and private land (Reid, Fernández-Giménez, and Galvin 2014). These initiatives share similar challenges that they must address to be successful. These include how to balance the sometimes competing needs of pastoral livelihoods and wildlife conservation, how to develop shared governance structures that are community-based but also recognized by formal government, and how to keep land in pastoral hands.

This paper focuses on the case of the private pastoral lands of Kitengela (or Athi-Kaputiei), Kenya, just south of and outside Nairobi National Park. Here, for the last 20 years, the Kaputiei Maasai community and their NGO and government supporters have worked together to keep pastoral land open for wildlife and reduce predator conflicts, through a series of conservation innovations over time (Matiko 2014). They do this by reducing incentives for land sales and land fragmentation through a land leasing program, by inventing and implementing new technology to repel predators, and by legalizing governance in a conservancy to support these efforts. The goal of this paper is to describe these efforts, their short and long-term impacts and look to future opportunities.
Methods and Study Site
This paper is a case study of this effort based on the lived experience of the senior author and some case literature. The second author also worked with the communities in the study area while the land leasing program was being established, doing research related to the program.

The Athi-Kaputiei ecosystem is a truncated part of much larger pastoral land that used to stretch from Mt Kenya to Mt Kilimanjaro, which supported the second largest wildebeest migration in Kenya (Reid et al., 2008). Today, the ecosystem includes Nairobi National Park to the north, the Kaputiei Maasai private lands south of the park. These lands abut the Keekonyokie Maasai lands to the west and large Machakos ranches to the southeast. This system is under immense pressure to provide land for Nairobi city residents, who then build houses, fences and businesses, entirely changing this open savanna into an urban corridor. Maasai still herd their cattle, sheep and goats here, but become confined to smaller and smaller blocks of land as the savanna develops. This land used to be common land but privatized in the 1980s. The ecosystem is also home to a dying migration of wildebeest that used to circulate between the park and pastoral lands in great numbers, but is much diminished today (Ogutu et al., 2013; Said et al., 2016). But significant wildlife still exist in Nairobi National Park and nearby pastoral lands.

Results and Discussion
In 2000, the non-profit, Friends of Nairobi National Park (FoNNaP), worked with the Maasai community to design and establish a land leasing program for pastoral landowners in this ecosystem (Matiko 2014). The goal of the program is to give pastoralists the incentive to keep their land open for both livestock and wildlife, by keeping possession of their land and not selling it. Participating landowners also agree to remove fences and poaching snares and avoid mining or planting crops. This program paid each participating landowner $4 (now $5)/acre/year, which was sufficiently attractive to encourage significant participation by landowners. The program is now under the umbrella of The Wildlife Foundation. This was one of the first biodiversity payment schemes in East Africa.

The Maasai and their partners decided to design the leasing program so that it supports education of their children (Parmisa personal observation). For example, the senior author was supported for some of his education by the leasing program. They thus make program payouts three times a year just when community members need it most for education: right when they owe school fees for their children. Since education is under a woman’s remit in a Maasai household, the women decide how this education benefit gets paid. Many women see how vulnerable their girls are to dropping out of school and decide to use the funds to pay the school fees for their female children. Also, the lease program disproportionately benefits poorer households, providing up to half of a family’s disposable income during hard times like droughts (Kristjanson et al., 2002).

From 2000 to about 2012, the lease program thrived with the support of significant grant funding from different donors, but this was not sustainable long term. So the Maasai community and partners searched for a more sustainable source, and settled on restoring an existing Wildlife Center on their land for secondary students from UK to support their program. This program provides the 1.5 million Ksh needed to run the leasing program each year. This innovation allowed the community to wean off the treadmill of grant funding, and also to run a school on their lands, which they also used for their own students.

Then the coronavirus pandemic struck in 2020 and the international students could not travel. Undaunted, the Maasai community and their partners launched into schooling for the local market, got some small local grants and managed
to keep the land leasing program running. However, if the pandemic continues, they will have further challenges to sustain this keystone program using their current business model.

A new opportunity to innovate further occurred with Kenya’s new 2010 constitution. This constitution decentralized the management of wildlife to the local level for the first time, allowing communities and landowners to manage wildlife in areas outside parks and reserves in Kenya. The Kenyan government then enacted the Wildlife Conservation and Management Act (2013), which recognized ‘conservancies, community wildlife associations, community scouts and County Wildlife Conservation and Compensation Committees’ (KWCA 2016):15. In response, many communities and landowners started establishing new community conservancies on their land, creating a conservation revolution at the local level in Kenya (Reid et al., 2016). A community conservancy is ‘land designated by a community or private land owner, groups of owners or corporate body for purposes of wildlife conservation and other compatible land uses’ (KWCA 2016):19.

In 2011, an 11-year old Maasai boy, Richard Turere, invented a way to protect Maasai wildlife from predation by lions and leopards using ‘lion lights’ (Turere 2013). Maasai string these lights around their livestock corrals and set them blinking at night time. This has served as a powerful deterrent for livestock predation in this community. The lights had a flaw, however, if one part of the line was cut, all the lights went off. Today, Maasai, with the help of conservation NGOs, install lights individually, each with their own solar power source and small battery, which also costs about half the price of the original string light.
Implications and the Future

The Kaputiei Maasai community has steadily innovated ways to meet the twin goals of supporting pastoral livelihoods and wildlife conservation in one of the most rapidly changing savannas in the world. As this system changes further, this community will have enormous pressure to surrender their land to the land sales market. In the face of this, the Maasai and their partners are pushing back, trying to reestablish some of the wildebeest migration by reconnecting Nairobi National Park to the Machakos ranches, through the government owned land or Portland Cement and the Export Processing zone. To reach the ranches, some pieces of land will need to be purchased or condemned for the purpose. In the middle of this corridor is the busy Namanga Road, where partners plan to build a wildlife overpass.

The land leasing program is also increasingly popular, with many additional landowners in the queue to join the program. If the pandemic wanes and international travel resumes, the conservancy and its leasing program will be in a good position to expand their program, when it will then be based on both local and international support.

One of the unintended impacts of the leasing program is on girls education. Today, the senior author observes that more girls are going to school than boys in his Maasai community, especially to university. Boys are often skipping university to go into local businesses. When girls are educated and boys are not, many Maasai girls choose to marry an educated man from another tribe, thus diluting Maasai culture over generations. Since educated men and women hold many of the levers of power in Kenya, we wonder how this movement of Maasai women out of Maasailand will affect Maasai society in the future.

In our observations across Maasailand, we find that this part of Maasailand is particularly innovative, partly because they have to be. Over a century ago, people observing Maasailand predicted its imminent demise, given the rapid cultural change that colonialism brought. But, clearly, innovation and problem solving is a cornerstone of Maasai culture, and we hope this habit and the Maasai people thrive far into the future.

Acknowledgements

The senior author would like to sincerely thank his family, Dr. Galvin Kathleen, The Wildlife Foundation and Naretunoi Community Conservancy for their support and contribution during the writing of this work. The second author thanks the International Livestock Research Institute, and the Dept of Ecosystem Science and Sustainability and the Center for Collaborative Conservation at CSU for support to do this work.

References


When good conservation becomes good economics – choice of policy scenarios

Said, M.Y.¹, Damania, R.², Desbureaux, S.², Scandizzo, P. L.², Mikou, M.², and Gohil, D.³

¹Institute for Climate Change and Adaptation, University of Nairobi, Kenya
²World Bank, Washington, USA
³Converge Independent Consultant, Nairobi, Kenya

Key words: Wildlife; conservancies; trade-offs; infrastructure; planning

Abstract
Wildlife populations in the Kenya rangelands are declining fast, including the charismatic species that attract tourists. Wildlife depends on reserve-adjacent land (including conservancies) for continued viability as it does on the protected areas. This recent study indicates investment in conservancies generates significantly higher multipliers—almost twice as high. This is a consequence of the vital role wildlife plays in the tourism value chain, with multiple direct and indirect connections to employment-generating activities in sectors with high multipliers, such as transportation and lodging. This study indicates that every dollar invested in conservation and wildlife tourism in Kenya could generate benefits that range from $3 to $20, with returns that increase with the level of investment. Such increasing returns reflect the ecological importance of connected natural habitats that are more productive in terms of the ecosystem services they provide and are also more resilient to droughts and other weather extremes. The evidence presented in this study suggests that there are vast opportunities to stop the dramatic collapse of wildlife populations and that investing in the tourism sector yields significant benefits. With the right infrastructure and the enabling environment to further develop the conservancy sector, there are tremendous opportunities to enhance growth through the conservation of wildlife assets in the Kenya rangelands.

Introduction
There is mounting evidence of catastrophic declines in the number and range of wildlife populations worldwide (Ceballos et al., 2017). Rapid human population growth, land-use changes, land fragmentation, infrastructure development (Sala 2000), poaching for trophy and bush meat (WWF 2007), climate change (Wiens 2016), outbreaks of infectious diseases (Dybas 2009), proliferation of firearms, weak law enforcement, poor governance, and poverty (Daskin and Pringle 2018) have all been blamed for the fall. In Kenya, the wildlife has declined precipitously, and for certain species catastrophically over the last 40 years. Kenya lost 68.4% of its wildlife between 1977 and 2016 (Ogutu et al., 2016).

In Kenya wildlife depends as much on adjacent land for continued viability as it does on the protected areas. Pressures around the parks are affecting wildlife within the parks. The way in which land outside of protected areas is utilized and managed will become a crucial determinant of the industry’s future. Expanding tourism to these areas remains among the most successful approaches that have been piloted. However, the feasibility of this approach depends upon economic incentives and the opportunity costs of land. A Computable General Equilibrium (CGE) model is used to estimate the economic consequences of wildlife loss and compare these consequences to alternative development pathways. And finally, we explore the alternative of road development but minimizing the impacts on wildlife numbers and the potential role of conservancies.

Methods
Analysis of drivers of wildlife decline
Nonparametric statistical models known as LOWESS regressions were used to investigate the
causal links, if any, between natural habitat loss in Kenya—increase in cropland in the rangelands and the distance to roads, loss of wildlife and distance to road, loss of wildlife, and human population density and wildlife loss and settlement. The wildlife data was sourced from the Directorate of Resource Surveys and Remote Sensing (DSRRS). The data was aggregated to a 10 x 10 km grid and covered 21 counties. The data was summed up into the 1980s (1977-1989), 1990s (1990-1999), and 2010s (2000-2016). The data on crop and settlement was sourced from ESA land use data, human population from WorldPop, roads from Michelin and DeLorme data for Kenya, and conservancies from Kenya Wildlife Conservation Association (KWCA) and Northern Rangeland Trust (NRT).

Computable General Equilibrium (CGE) model

In this study CGE model can be used to determine the effects of investment in different sectors by examining the multipliers and the overall impact on key economic variables of interest. Three policy simulations were conducted—i) trade-offs between road construction and wildlife tourism ii) investment and capital productivity in conservancies and wildlife conservation, and iii) role of conservancies. To explore this issue in a rigorous manner, the analysis employed a computable general equilibrium (CGE) model that divides the economy into two regions—North and south. The model tracks the contribution and linkages between various economic activities and provides an indication of the economic consequences of alternative development strategies.

The data used in CGE model were agriculture, livestock, forestry, wildlife, parks, conservancies, water biodiversity, mining, food, beverages and tobacco, all other manufacturing, distribution water, utilities, construction, trade, accommodation and restaurant, lodge, transport, information and communication, financial and insurance activities, real estate, business and administrative, health and social work, education, park tourism, beach tourism, cultural tourism, and business tourism.

Results and Discussion

Wildlife trends

The results generally show that the closer a grid cell was to a road, the faster the conversion of natural habitat to farms and settlements (Figure 1a and 1b), which consequently impacted wildlife (Figure 1c). On average, the extent of conversion of natural habitats in Kenya was especially stark within 20 kilometers of a road, particularly in terms of conversion into settlements. Thereafter, the transformation of natural habitat into cropland slowly decreases and becomes negligible for settlements.

Trade-offs between road construction and wildlife tourism

Three critical features of the Kenyan economy become evident from the CGE analysis (Table 1). First, investment multipliers for construction appear to be linear (i.e., they do not vary with the scale of the investment). Second, the construction multipliers are lower than the multipliers associated with conservancies and wildlife conservation activities. This is due to the greater complexity and connectivity of tourism value chains and the complementarity of wildlife tourism with other sectors of the economy. Third, in contrast to the construction sector, conservation investments exhibit scale effects and increase with the amount invested. These effects emerge as a consequence of deeper linkages to other parts of the economy.
Investment and capital productivity in conservancies and wildlife conservation

Tables 2 and 3 show the results of the simulations of a hypothetical scenario that involves combining “smart” technologies with traditional conservation techniques through productivity increases and resource allocation. The Spatial Monitoring and Reporting Tool (SMART), already in use in some conservancies in Kenya, is one such example of a new technology. It is a protected area management tool designed to measure, evaluate, and improve the overall effectiveness of law enforcement patrols. In this simulation, the model predicts synergistic effects with more than proportional increases of the multipliers. The impact on incomes is large and more balanced across regions and income groups, with the North and the poor reaping the considerable benefits. In sum, “smart” investments in conservation could be a “win-win” policy with huge gains for both regions, a healthy balanced expansion of the economy, and larger benefits for the rural poor. Wildlife in Kenya, especially in the North of the country, represents a lucrative economic asset whose contribution has been underestimated and potentially unrealized. The CGE assessment indicates that every dollar invested in conservation and wildlife tourism could generate benefits that range from $3 to $20.

Table 1: CGE Investment impact multipliers

<table>
<thead>
<tr>
<th>Sector</th>
<th>Investments ($, million)</th>
<th>Value added multipliers ($, million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Construction</td>
<td>1.96</td>
<td>1.97</td>
</tr>
<tr>
<td>Conservancies</td>
<td>4.28</td>
<td>4.41</td>
</tr>
<tr>
<td>Wildlife</td>
<td>4.26</td>
<td>4.39</td>
</tr>
<tr>
<td>Source: Damania et al., 2019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Doubling investment and capital productivity in conservancies and wildlife conservation: impact on value added

<table>
<thead>
<tr>
<th>Value Added ($ millions)</th>
<th>South (Region A)</th>
<th>North (Region B)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base case</td>
<td>Simulation</td>
<td>Base case</td>
</tr>
<tr>
<td>Labor</td>
<td>19,374.90</td>
<td>22,029.30</td>
<td>1,764.40</td>
</tr>
<tr>
<td>Capital</td>
<td>31,278.20</td>
<td>36,626.40</td>
<td>2,607.40</td>
</tr>
<tr>
<td>Land</td>
<td>5,163.20</td>
<td>9,958.40</td>
<td>895.40</td>
</tr>
<tr>
<td>Eco services</td>
<td>1,214.00</td>
<td>3,142.90</td>
<td>700.30</td>
</tr>
</tbody>
</table>

Table 3: Doubling investment and capital productivity in conservancies and wildlife conservation: impact on income distribution

<table>
<thead>
<tr>
<th>Value Added ($ millions)</th>
<th>South (Region A)</th>
<th>North (Region B)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base case</td>
<td>Simulation</td>
<td>Base case</td>
</tr>
<tr>
<td>Enterprises</td>
<td>31,278.2</td>
<td>36,626.5</td>
<td>2,607.4</td>
</tr>
<tr>
<td>Rural poor</td>
<td>7,998.5</td>
<td>10,769.4</td>
<td>1,683.9</td>
</tr>
<tr>
<td>Rural non-poor</td>
<td>13,069.5</td>
<td>17,492.1</td>
<td>2,607.0</td>
</tr>
<tr>
<td>Urban poor</td>
<td>1,437.9</td>
<td>1,701.1</td>
<td>214.8</td>
</tr>
<tr>
<td>Urban non poor</td>
<td>36,365.7</td>
<td>43,777.0</td>
<td>6,480.9</td>
</tr>
<tr>
<td>Invest in conservancies</td>
<td>285.4</td>
<td>570.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Invest in wildlife</td>
<td>1,598.8</td>
<td>3,197.5</td>
<td>529.7</td>
</tr>
<tr>
<td>Source: Damania et al., 2019</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Role of conservancies

Conservancies can play an important role in diversifying the tourism product and securing critical habitats while generating economic activity. There are currently more than 166 conservancies spread across Kenya’s 28 counties. They cover an area larger than the country’s national parks, are home to more than 22 percent of Kenya’s ungulate wildlife biomass, and have some of the highest densities of wildlife in the country. 18 out of the 20 zones with the highest density of wildlife are in conservancies and not parks. Conservancies create buffers around parks and maintain connectivity between several ecosystems. In essence, conservancies are critical to the resilience of wildlife.

Wildlife Friendly Roads

This report finds that roads’ judicious location can connect much of the country to centers of economic activity while avoiding potential losses of wildlife. This is because much of Kenya’s densely populated western counties require rural roads, but they are also areas with low levels of wildlife and tourism potential. Figure 2 illustrates one such example and shows that with sophisticated planning approaches, equivalent “connections” can be made with much more limited wildlife losses (compare the green and orange lines). Under the original model, wildlife is lost after approximately 500,000 people are connected to the road network (green line). In comparison, wildlife loss in the modified model only happens after 2 million people access these improved roads. Further, while wildlife loss in the first model skyrockets after 1.5 million people are connected, under the modified model, this happens after 2.5 million people gain access to the road network. Hence, most people could be connected to the network while avoiding negative impacts on wildlife. In sum, deploying smarter, greener approaches to infrastructure also makes economic sense. Achieving this equilibrium will call for more sophisticated planning approaches that recognize both the benefits as well as the adverse impacts for both the economy and wildlife.

Figure 2: Factoring in wildlife constraints significantly reduces the impact of new roads on wildlife

Source data and information: Damania et al., 2019 and Photo: constructionreviewonline.com

Conclusion

Development of large strategic infrastructure to promote connectivity can be consistent with efforts to conserve natural assets, which also contribute to economic growth. Tools are available that allow planners to predict the impacts of their decision on wildlife—a key economic asset. The same tools can be used to predict how to meet other development objectives more effectively. Through careful and strategic planning, spending on infrastructure can be rendered more effective and more conducive to growth and poverty reduction and less impactful on wildlife and the economic opportunities that they bring. The additional complexity and cost of planning, such as in infrastructure, would be justified by the vastly greater benefits that would accrue to the country.

Acknowledgments

The World Bank Group supported the study. We thank the Directorate of Resources Surveys and Remote Sensing for sharing the wildlife data. The Kenya Wildlife Conservancy Association for availing the spatial and temporal data on conservancy, conservancy establishment dates, and revenues.
References


WWF (2017) Poaching and illegal wildlife trade, WWF, Switzerland.
THEME 6: PASTORALISM, SOCIAL, GENDER AND POLICY ISSUES

Topic: Gender and Indigenous Perspectives For Sustainable Rangelands: Gendering and Decolonizing Pastoralist Studies and Rangeland Conservation
Knowledge about and knowledge with: contributions from feminist research to knowledge co-production for pastoral systems

Ravera F.¹, Fernández-Giménez M.², Oteros-Rozas E.³

¹Department of Geography, University of Girona, Girona, Catalunya, Spain, ² Dept. of Forest and Rangeland Stewardship, Colorado State University, Fort Collins, CO 80523-1472 ³ Chair for Agroecology, Universitat Vic, Vic, Catalunya, Spain

Keywords: Epistemological pluralism, extensive livestock management, feminist rangeland and pastoralism research, Spain, women pastoralists

Abstract
Globally, the gender dynamics of rangeland social-ecological systems have received scant attention. Further, research paradigms, methods and methodologies that leave little room for equitable engagement with research participants and genuine action-oriented research-practice partnerships dominate in pastoralist/rangeland studies. Our research is informed by a feminist philosophy of science and based on decolonial and feminist political ecology studies that focus on gendered science and knowledge production. Feminist research calls for reflection on who produces knowledge and how such knowledge is used and shared. Feminist practices such as reciprocity, care, and positionality, cultivate awareness of the power dynamics embedded in the research process and motivate us as researchers to counteract asymmetrical or extractive relationships when we identify them. In this paper we first introduce the principles of our feminist research, and then reflect on our experience as researchers and as activists or participants in the Spanish and Catalan networks of women shepherdesses and livestock operators.

Introduction
In the last few decades, several approaches have emerged oriented towards transforming the practice of science to focus on societal problems and engage multiple social actors in knowledge co-production (Knapp et al., 2019). First, in order to understand wicked problems, science processes are incorporating multiple disciplines (Klenk and Meehan 2017). Second, in order to produce knowledge that may support societal solutions to wicked problems and involve the voices of those affected by such problems, scientists increasingly recognize the need to collaborate with other members of society, learn together, and implement co-produced knowledge in socially legitimate actions (Lemos and Morehouse 2005). Several scholars have explored the transformative effect of transdisciplinary processes and co-production of knowledge in environmental science (Klenk y Meehan 2017), while others highlight failures in achieving empowerment and societal transformation, increasing unequal power relations (Turnhout et al., 2020). Feminist and decolonial studies of science have profoundly transgressed mainstream epistemological and methodological approaches and logic of research (Lanza Rivers 2019). In this paper we present feminist studies of science and decolonial feminism that focus on the process of knowledge co-production and integrate science and activism (see similarly Irene-Iniesta et al., 2020) grouped in three categories of principles: 1) positionality and reflexivity, 2) embodiment and co-production of knowledge and 3) reciprocity and ethic of care that may bring transformation and emancipation. Reflexivity refers to the examination of one’s own beliefs, judgments and practices during the research process and how these may have influenced the research. In feminist practice it is important to reflect about choices made about what to study and what studies, that are, according to cultural studies, culturally and socially bounded decisions that reflect power and values (Schnabel, 2014). Such critical reflection is also related to power dynamics that may exist between researchers and subjects of research and the impact in the research and in generating and circulating knowledge (Rose 1997). This concept is defined by feminist studies of science as positionality. Feminist studies denounce that based on a biased vision of knowledge as universal, objective and rational, science has legitimated its powerful position with respect to other knowing systems. As researchers we should
trace how our social position, as urban, white and educated subjects, may shape knowledge production (Faria and Mollet, 2016). Specifically, decolonial feminist studies have evidenced the relevance of taking into account multiple voices, knowledge and knowing systems, such as from indigenous people and farmers’ systems, that may understand and represent relationships with nature and its management very differently from western science, within processes of knowledge co-production. However, the efforts could not be only based on inclusion of women’s or indigenous voices into the process. Frequently, structural barriers of intersectional discriminations of voices, based on country of origin, ethnicity, education system, race, and other individual and collective social identities, should be recognized. Similarly, researchers in feminist political ecology and feminist geography (Sultana, 2014; Mollet and Faria, 2013) called for environmental studies to move ‘beyond gender’, to include analyses of multiple and intersecting power inequities and (un)justice and challenge dominant assumptions of western knowledge systems (Harris, 2015) which constitute barriers for effective co-production. Feminist theorists have also invited researchers to overcome the duality of mind and body challenging the positivist science-based knowledge production. This calls for novel ontological but also epistemological approaches that have often led to new methodological proposals of working with literature and arts (Benessia et al., 2012). Drawing from activist research and decolonial anthropology, epistemic-corporeal workshops consider body and emotions as spaces from which to explore collaboratively (researchers and non-) embodied and experiential knowledge. Finally, a commitment to reciprocity and care ethic emerges from the practice of reflexivity that motivates researchers to counteract asymmetrical or extractive relationships when we identify them (Smith 1999). It implies demonstrating long-term commitment to local research partners, pursuing questions and needs they identify, engaging with them as co-researchers and returning results for a better understanding, offering training and capacity building. It also implies nurturing a new culture of collaborations, shared learning and relationships of trust, respect of time and conviviality, essential for understanding complex social and spatial processes (Caretta 2019). Moreover such ethic should orient our way of conceiving and doing science. Slow and care-oriented scholarship in geography have recently challenged a neoliberal model of science, based on extractive, transactional, competitive, and exploitative relationships among researchers and of these with social actors that intervene in research. (Mountz et al., 2015). To date, there are a growing number of rangeland studies with a transdisciplinary co-production knowledge approach (Reid et al., 2020), but feminist perspectives in rangeland research are almost entirely absent (Wilmer and Fernandez-Gimenez 2016).

In this paper we reflect on our application of the feminist research principles of reflexivity, positionality, knowledge co-production, embodiment, reciprocity and ethics of care in the context of our experience researching with and about women pastoralists in Spain. By doing so, we provide an empirically grounded theoretical and methodological context for the other papers in this session. We hope that such reflections may offer one example to inspire others towards transformative and emancipatory future research.

**Context and Methods**

Until recently, women have been largely invisible participants in extensive livestock management systems in most areas of Spain. Further, little to no research exists on women’s roles, knowledge or experiences in these systems, despite the fact that women’s participation in agriculture is highest in the livestock sector (Majoral and Sánchez Aguilera 2002). Yet understanding women pastoralists is critical. The lack of women in pastoralism may compromise generational renewal in these management systems, further fostering rural masculinization and ultimately abandonment (Fernández-Giménez and Fillat Estaque 2012, Oteros-Rozas et al., 2013). Further, women may play key roles in both conserving and transmitting management knowledge and culture, and in innovating and transforming extensive pastoral systems towards greater sustainability (Fernández-Giménez, Ravera and Oteros-Rozas, submitted). To address the lack of research on and with women pastoralists in Spain, we carried out two different research projects that aimed to understand women’s lives and roles in extensive pastoral systems using in-depth life-history interviews coupled with participant observation and participatory workshops with research participants. For this paper, we each reflected individually on our experiences in these action-research processes in relation to feminist research principles. We then identified common themes and individual variations among the 3 authors’ experiences to extract lessons learned from applying feminist principles to our research on Spanish women pastoralists.

**Findings and Lessons learned from our experiences**

**Positionality and Reflexivity**
The three authors have in common advanced education in both applied ecology and social sciences, and grew up in large cities (EOR, FR) or towns (MFG). We each gained experience in rural life as farm/ranch workers (MFG) and/or researchers in rural settings (all). EOR is Spanish, while FR is Italian now permanently residing in Spain and MFG is from the US of Spanish heritage. MFG previously lived for a year and carried out research in one study site and FR conducts long-term field-work research in the Pyrenees, while EOR developed extensive fieldwork among transhumant pastoralists for 4 years and since 2016 helped facilitate a network of Spanish women pastoralists, several of whom participated in the study. Both FR and EOR identify as feminist agro-ecology activists as well as researchers, while MFG identifies as a researcher and advocate for extensive pastoralism. Both EOR and FR relocated from cities to small rural communities during the research. MFG is in her late 50s, FR in her 40s and EOR in her 30s. Our backgrounds thus positioned each of us in different ways in relation to our various study communities and participants, which sometimes dissolved and sometimes reinforced traditional researcher-participant dynamics. On one hand, we recognized our privilege as highly-educated urban residents with greater economic security and information access than most of our rural participants. On the other, our own life histories as women with experiences like parenting, losing a parent, or moving from a city to a village, created a bond of shared experience with different participants. MFG and FR both benefited to some extent from being “foreigners,” releasing us from some expectations, and garnering increased appreciation for our skills in local languages (Catalan for FR, Spanish for MFG). EOR had close personal relationships with some participants due to her facilitator role, and FR had personal friendships with some Catalan women participants, which provided additional insight in our interpretations. Each of us, thus, navigated multiple and sometimes conflicting positions such as researcher, activist/advocate, facilitator, and/or friend, relative to our participants and to the extensive livestock sector. Balancing these different roles and positions required adapting our research objectives and rhythms, and working to maintain trust and transparency with our participants and each other. Building upon our awareness of our positionalities, we practiced reflexivity by examining how our positions, beliefs and practices affected the research, and the power dynamics therein, especially in the context of a particular political and social moment. FR reflected on how she is rewarded for research publications and grants in which the “local communities are the protagonists,” but for which they receive little credit. She counteracted this imbalance by engaging women in her study site in arts activities through which they communicate key findings and messages from the research to a wider audience. EOR leveraged her facilitator and activist roles to bring our research participants to scientific conferences and international policy forums, where their voices directly reached a broad audience. MFG recognized her own developing understanding of feminist theory and practice through the project, and in the light of terrible racial injustices in her own country, critically reflected on the limitations of our research in not including participants from diverse racial and ethnic backgrounds within Spain. Our different ages, experiences and political perspectives also shaped what we emphasized in our data interpretations. For example, FR tended to emphasize the importance of newcomers women in transforming agrifood systems, while MFG was deeply interested in the contributions of older “traditional” rural women to both conservation and innovation in extensive pastoral systems. Ongoing reflexivity through individual and collective critical examination supports rigorous qualitative analysis and challenge us to continually disrupt and redress power differentials in pastoral/rangeland research.

The process: co-production of knowledge and embodiment

We have addressed co-production, knowledge pluralism and embodiment by documenting and valuing women’s knowledge and experiences via interviews and gatherings, incorporating artistic approaches, engaging them as co-researchers to the extent possible in interpretation, discussions of how to present and use the data and offering of co-authorship. First, we chose the sample of women to interview so that it could be comprehensive of a diversity of situations of women in pastoralism, e.g. in terms of age, family-relationship (daughters, mothers, partners of other pastoralists, newcomers into farming…), origin (urban, rural…) geographical area of Spain, type of livestock and breeds, production model or relationship with and participation in social organisations, among other criteria. Interviews were held during long hours (usually spending at least a day with each participant), combining formal and informal conversations, partially recorded, in the field accompanying herding or other farming tasks, or at their homes. Gatherings took place in different settings. While we tried to hold them in comfortable places that allowed for conviviality, this was not always possible. However, this allowed us to notice and reflect about the differences in the process between the
case where the gathering was held over a weekend of coexistence in a leased vacation home, with women participating and sharing also for instance home-made food and relaxed and intimate moments; or when the gathering was held in a conventional meeting room in a city centre, over a day with a lunch in a restaurant. Choosing, arranging and observing the use of the physical spaces where interviews and gatherings took place, and their influence on participants’ and researchers’ moods, attitudes, comfort, easiness, also had an influence in the outcomes of the process, as a lived and embodied experience. We observed that food had always a very central and special role in the shared spaces: whether it was a lunch together with an interviewee at her home or a restaurant, mutual gifts exchanged as a form of gratitude, a shepherdess and cheese maker bringing her cheese to a public event, an incredibly diverse lunch with 10 women serving their own products and home-made food and displaying their proudness about their own gastronomic identities, or the relaxed atmosphere of them sitting around a table in a restaurant, enjoying a special day being served the food without having needed to prepare it themselves. Food, due to its sensual, visceral nature has been considered a strategic place from which to begin to understand identity, difference and power. Feminist geographers have called for a “visceral approach to food” through which observing how the body offers a domain that makes room for the construction of political claims that are paradoxically ‘outside’ of normative discourse, despite also being fully ‘inside’.

Women farmers are ultimately food producers, so that food in feminist research approaches opens up a significantly different space for expression and exploration of identities, political claims and overall embodiment. Another approach we have incorporated in our work in order to addressed embodiment of identities, experiences and knowledge, has been that of arts. Based on image theatre, a tool within social theatre and theatre of the oppressed, we built subsequent body-statues with one’s and others’ bodies and totems representing their identity as livestock farmers and women, which participants were invited to bring from home. Participants and researchers played around and consciously expressed our embodied identities and our relationship with extensive livestock farming. We could also share our life histories, fears, vulnerabilities, pride, etc. and learn about others’, not only with words, through rational and cognitive experiences, but also through a physical and emotional experiences. As researchers, these kind of proposals require skills and a familiarity, which are only achieved with time, sensitivity and care. Other artistic approaches we explored were literary and visual arts (a comic and an itinerant exhibition), in order to capture not only through rationality and verbal discourses, but rather through emotions, the key messages that shepherdesses would communicate to the society and offer them the chance to do so, working with local artists. They appreciated these experiences as a form of co-production, given their involvement in the exhibition with a space for telling their stories through artistic means.

**Reciprocity and ethic of care for transformation**

Caring the process and the relationships with participants motivates us as researchers to counteract asymmetrical or extractive relationships when we identify them. We do this by demonstrating our commitment to local partnerships, pursuing questions they identify, engaging with them as co-researchers by sharing interview transcripts with individuals and then preliminary results at regional workshops, involving participants to participate in artistic communication of the results of the research. We ensured that the results are returned to the community in a form they can understand and use and we invited participants to co-author papers, even if those who expressed interest have not had time to follow up. As previously suggested take care of the others includes for us to make attention both by researchers and participants to physical needs of everyone, including physical health, carefully choosing the spaces for interviews and activities that may favour conviviality, inviting people to spend time together. Giving space and legitimacy to the “personal” (sharing life experiences, needs, opinions, dancing and singing…) is a way to deconstruct the power relation of research, seen as extraction of information. The team aspires to support women, especially those already organized via GeR or ramaderes.cat, in advancing their self-defined goals/agenda for increasing visibility of and support for women herders, as well as extensive livestock production overall. In the case of EOR, as co-facilitator de GeR, and FR, who has spent years with local communities in the Pyrenees, personal relationships the space of research has been transformed in a space of confidence, listening and friendship with women. Such listening space may in some cases catalyzing changes in self-perception, empowering and increasing the willingness to participate in other experiences with other women. In the case of EOR, she supported GeR in technicalities as well as emotionally, in the case of FR she applied situated ethnography that include share hours in the field, working with shepherdesses and share spaces of socialization and collective meetings. This activist commitment with pastoralist community also extended out of the locality of
the studies and during the pandemic FR and EOR invited shepherdesses and women operators to be part of a feminist agroecological network to discuss problems, launch campaigns, participate in analysing solutions for post COVID measures and create a space of mutual support among women researchers and farmers. Recently, they also challenged the uncomfortable discussion among feminist antispeciesism and agroecological feminist. The conflict reflects a recurrent question of abandonment and undervaluation of the rural world by a urban culture in an asymmetric power relationship that normatively reproduces in public opinions the narrative that defines which experiences have value and who has the legitimate technical and scientific knowledge to take decisions. Specifically, urban, highly educated and academically supported anti-speciesism and vegan feminist movements are opposed to women pastoralists, some of whom also self-identify as feminists. A new campaign in defence of rural feminism is currently supported. We also experimented with limitations and tensions. First, we converge in considering the difficulties to maintain in the distance the caring process, especially when during the pandemia the lock down only permitted virtual calls that were transformed in the daily practice of researchers but were an extra time demanded to women farmers. This fleshed out a always latent tension observed in the experiences of the three researchers: among between care of the time and space together between having a space and time together with women participants, as a care space (e.g. during the interviews for self-empowerment and acknowledgement as knowledge holders; during the workshops as a collective space of enjoyment) versus consuming energy and time that may add workload to women shepherds. Additionally, in several occasions researchers reflected with women on the risks and impacts assumed by some women in order to participate in the spaces of the research. They left home to assist the workshops, being away from care duties and farm work for several days, with “unknown” people, that in a patriarchal society as the rural Spanish society were suspicious for partners and possible source of betrayal and accusations. Finally, extremely sensitive information in terms of women’s emotional and physical wellbeing and security was handled during the interviews and workshops. In some cases, they shared hard experiences (e.g. of violence or disrespect from partners or other family members) in moments of intimacy, as it happened in the workshops of GeR. In several occasions the researchers decided to prioritize spending more time for listening and empathising more than only reach research objectives, despite the lack of tools and experience to handle such situations.

Conclusions
Overall our own experiences have shown that processes of co-production may be reinforced by feminist principles in order to contribute to societal transformations. Along the process we have had an internal reflection among the three of us, balancing intuition, previous experiences in participatory(-action-) research in practice and with feminist theoretical frameworks. As a result of our reflection process, we recognise our privileges as researchers in the acknowledgement and credit of the knowledge we produce, getting social and academic attention and rewarding that the communities barely receive. We also recognize that to be transformative, the co-production processes should overcome the boundaries of projects in itself and engage with the wider political context. We finally observed that the ability to more deeply engage participants has been hindered by our geographic dispersion, constraints on the women’s time, as well as the time of the research team, and lately the COVID19 pandemic, which has impeded almost all physical encounters and only allowed the continuity of virtual interactions.

Acknowledgements
Fundings for this work were provided by the Asociación Trashumancia y Naturaleza, MAVA Foundation, Fulbright Global Scholar Award, AXA Research Fund (2016), the spanish Ministry of Science, Innovation and Universities. We are deeply grateful to the women who participated in this study as interviewees and workshop participants, and who shared their lives and homes with us.

References
Faria C and Mollett S. 2016. Critical feminist reflexivity and the politics of whiteness in the ‘field’, Gender, Place & Culture, 23:1, 79-93


Sustainable development and the transformation of female rural labor: The case of woman cattle ranchers in Uruguay

Courdin, V

Key words: women’s work; rural development; livestock farming; Uruguay; gender and ranching

Abstract
Internationally, rural women are considered key to sustainable development. However, in the Uruguayan livestock sector, women’s work is largely unrecognized by public policy makers, causing younger women to migrate, and resulting in the “masculinization” of livestock husbandry. In Uruguay, extensive livestock production (range livestock) analysis has historically ignored the genuinely productive role that women play in rangelands, limiting the visibility of their action to reproductive activities while ignoring their importance in terms of income generation, herd management, networking, strategic planning, etc. Although family production integrates women, their work is often invisible, subsumed within domestic chores or seen as “helping” the husband, considering him the only “producer.” This paper reflects on the role of women in the organization of labor in extensive livestock systems while providing elements to elucidate the relationship between gender and livestock production strategies. Through the implementation of semi-structured interviews and participant observation dynamics, we analyzed the productive practices of women dedicated to cattle ranching in the Northern littoral (“Litoral Norte”) grasslands of Uruguay. Our analysis focused on three main areas: i) a typology of the main identified profiles of rural women involved in livestock production (principal decision-maker, collaborator, job executor) and farm and time management options; ii) the different dynamics of decision-making, according to the previously cited typology of women’s profiles and roles; and iii) women’s subjective perceptions and visions of the transformations experienced in their productive activities. Results reveal the relative heterogeneity of female work configurations in family livestock production systems. Main labor differences evidenced in the production unit are rooted in deeper structural inequalities originated in the traditional place’s women are assigned in the Uruguayan society at large. In that regard, our research identified five factors that influence the position, profile, and labor roles of women in extensive livestock production in Uruguay: i) the symbolic power position and relationship of women with and within their families, ii) their socioeconomic background, iii) the relative size of their farms in number of hectares, iv) the presence of labor support/employees, and v) the formal tenure of land and animals. We conclude that the rich diversity of women’s involvement strategies in ranching is linked to a delicate articulation between their families, their professional and their social universes (including their expectations for the future), all of which offer women a span of different degrees of autonomy to determine their time management, the performance of productive tasks, and their own identities.

Introduction
In Uruguay, the women who lived in productive units in 2011 were 39,257 out of a total of 106,961 people. Between 1970 and 2011, the proportion of women in the total population decrease from 43.4 to 36.7% (MGAP-DIEA, 2011). This evolution shows that historically women have had a lesser presence than men in the field, due in part to the country’s predominant production system, extensive cattle ranching, which has traditionally almost exclusively involved men. On the other hand, since the fifties, the processes of land concentration and mechanization, have reduced family production (Rossi, 2010), in which women had a prevalent place. The statistics reflect the gender inequalities women experience in Uruguayan agriculture. The statistics also obscure the work that many women carry out on farms as unpaid workers. Consequently, the rural environment is experiencing a sustained process of depopulation, due in part to women’s emigration to urban areas, especially young women who seek to continue with their studies and obtain job opportunities (Chiappe, 2005).

Does rural women’s work count?
Economics and sociology traditionally consider work to be activities related to the economic production of goods and services that fall within the market circuit. Within the population of rural women, three sub-populations can be differentiated: agricultural producers (heads and co-heads of farms), wage earners (permanent or temporary), and women with non-agricultural rural employment (FAO, 2013). This leads many studies on gender and rural work to ignore that the boundaries that separate these sub-populations are by no means hermetic, since rural women are essentially multi-active, combining, simultaneously or successively, wage-earning, or unpaid agricultural activities, with non-agricultural activities under different conditions. Likewise, rural women shift very easily from being active to inactive\(^1\) (or vice versa) in livestock activity, depending on family circumstances or the environment, a fact often overlooked by research (Courdin, 2008). This mobility and multi-belonging to different categories strongly hinders women’s visibility and characterization, giving rise to hugely different figures, not very comparable and, generally, very underestimated (FAO, 2013).

**Methodology**

Based on semi-structured interviews with 13 rural women from the North Coast region of the country, who present profiles of principal decision-maker, collaborator, observer, we sought to identify the different degrees of involvement of women in livestock production families. Principal decision-maker: woman who make decisions related to the operation of the production system and the management of the farm. Collaborator: woman who collaborate in decision making with the boss. Observer: woman who do not participate in decision making. These profiles, commonly perceived in rural livestock areas of the country, were taken from previous studies (Courdin, 2008; Litre, 2010). We also investigated women’s perceptions of their roles and the changes in gender relations in Uruguayan livestock production. We identified initial interviewees fitting the three profiles with assistance from Extension technicians and selected subsequent participants using the snowball method (Atkinson and Flint, 2004). From the analysis of the discourse of each of the interviews, we identified categories and indicators that allowed us to describe the type and level of involvement of women in the productive units. We also characterized their organization of work, identifying the factors that affect their roles, and deepening knowledge of their realities.

**Results**

The main practices developed by women in livestock production units can be organized into three categories: a) related to the functioning of the production system, b) linked to the management of the farm, and c) concerning the functioning of the home and family. The three groups contribute to the generation of direct income and to the reproduction of the family-farm unit. Work with animals in pens and field trips emerge as the main tasks within the first category. In the second, accounting and record-taking are the main tasks. The last category includes reproductive activities. Depending on the identified profiles of women and the degrees of involvement in the activities, we differentiated three types of women.

**Women leaders: principal decision-maker of livestock operation**

Women leaders are responsible for the productive unit and involved in the tasks that are carried out there. They are generally single or widowed, without dependent children, and who have accessed to the leadership of the productive unit due to their social condition (inheritance, widowhood, etc.). However, women maintain that the occupation of these spaces has been by choice, given their taste for rural activity, and not by imposition. At the national level (MGAP-DIEA, 2018), women who oversee livestock farms are 24% of all farms.

For the operation of the system, they have salaried labor (always male), to facilitate daily work, especially in tasks that require physical effort such as handling animals, maintaining fences, using heavy tools, etc. This does not imply a decrease in the participation of women in daily work, but rather they assume responsibility for planning work, generating authority when giving orders and legitimizing their decisions when managing the productive unit. Some of these women have experienced difficulties in their relationships with staff due to the “machismo” in rural areas, which positions the woman as incapable of leading decision-making spaces (Courdin, 2008).

Women “heads” are exclusively responsible for the decision-making process. However, there are some differences in the procedures of economic and productive decisions. Most of the economic decisions are made individually, reflecting the independence and personal freedom of these women regarding the management of their income. In contrast, productive decisions are made at two levels: i) through informal dialogue: with a close relative, with the permanent wage

---

\(^1\) The inactivity of women in livestock activity refers to the relegation of their involvement in work within the activity as a result of the birth of a child, the illness of a family member, etc.
earner or with a neighbor who is considered a mentor due to experience in the activity; and/or ii) through a formal dialogue with a professional belonging to an agricultural extension entity. The predominant level is the first (informal dialogue), since it allows them to easily channel some affective or aesthetic criteria (such as the choice of breed, the selection of animals, etc.) that are sometimes questioned by professionals.

One of the characteristics that differentiates women leaders and is typical of the profile is having a flexible and open attitude to new information. This means that women heads of production units are prone to “listen” to professionals, more predisposed to changes in their decisions regarding the operation of the production system and the incorporation of techniques and technologies that, in their opinion, allow them to improve their operations. Their interest in continuous learning and productive challenges lead them to participate in training activities, technical workshops and to receive extension workers in their productive unit. The relationship these women establish with technicians constitutes a learning process for both parties, being for these women an opportunity to demonstrate a different way of producing and for the professionals to understand a new sociocultural conception of managing a productive unit.

Shared work: collaborator of exploitation

Women “co-heads” share the productive unit with their partners and children. The presence of the man within the productive unit leads to these women not being able to play a leadership role (“heads”) and being conditioned to share leadership with him.

The main difference with the previous group does not lie in the task’s co-head women carry out, but in how they carry them out. Regarding productive activities, these women are involved in tasks carried out close to the domestic sphere, as a strategy not to neglect family dynamics, especially when they have children. They participate in activities with animals carried out in pens (health care, handling operations, etc.), their presence being less in field trips. Although these women’s role is to collaborate and they are not essential for work, many participate actively in the work sharing equal conditions with their partners (in terms of the amount of work and the importance attributed to it for both genders). This low appreciation attributed to women may be due to the fears they face daily within the family and in society, of occupying, sometimes, levels higher than men (Niedworok, 1986).

The “co-bosses” who are more involved with the operation of the production unit actively participate in tasks related to management, such as accounting and record-taking. This type of activity within the domestic sphere is compatible with other household activities and allows women to develop as responsible persons. Managing numbers, records and technical information requires “skills” that are more present in women, as they have a higher degree of educational training than men (MGAP-DIEA, 2018), which makes the task easier for them.

These co-head women’s participation in relevant farm management activities increases their self-esteem given the greater visibility and recognition of their work, which, although it is usually seen as helping male work, in some cases is perceived as a partnership. Likewise, in the decision-making process, it positions them in a negotiation space that allows them to exchange opinions in a more fluid dialogue regarding the administrative and sometimes animal management decisions. Despite this, not all of them actively participate in this process, since they consider that the one who should have the “last word” is the head of the operation. This is the product of a socialization process, where women incorporate certain guidelines, codes and social norms that position them in subordination to the “boss”, who is a man (Jelin, 2010).

In this group of women, reproductive work, with very few exceptions, is exclusively female. This differential distribution of tasks is associated with the sociocultural conceptions that families have, where the man is responsible for productive work, defined as that of a social and collective nature that generates social wealth, while the woman is responsible for care of children and the home, reproductive work (Courdin et al., 2014). This gender division of tasks has contributed to the fact that women “co-bosses” continue to be seen as “help” in productive tasks and as responsible for reproductive tasks, socially conditioning their independence and personal freedom.

Distant: observer on the operation

The “observer” women live with their families on farms. These women are involved little with the operation of the farm, not participating in any of the tasks of the production system. The tasks they perform have to do with taking care of the garden and small animals for the family’s own consumption. Their low participation is due to the lack of interest and/or the absence of space to participate in the activities of the productive unit. This reflects the strong patriarchal role of the men who accompany them, and the low value that they attribute to women in rural tasks (Barthez, 2005).
The “observer” women define themselves as shy, reserved, and consider that their minimal formal education conditions them not to express opinions on the productive unit. Likewise, their role only in domestic activities based on their concern for the care of the family and the home inhibits personal development, which under the patriarchal vision that conceptualizes women as “housewives”, hinders their empowerment and restricts their autonomy, decision-making capacity, self-confidence, and security. These subjective evaluations of work not only account for myths and beliefs based on a pattern of traditional gender roles in the field, but also respond to an objective reality base due to social stereotypes.

**Home, Family and Farm: A Crossroads**

In contrast to the productive activities of the farm, reproductive activities, in addition to being carried out almost exclusively by the women of the three profiles studied, continue to be their responsibility. The collaboration of men in child-rearing and house-keeping activities is very low and occasional (when the woman is ill, etc.), although women increase their working hours in tasks related to livestock operation. The double working hours of women forces them to adjust the time to their multiple responsibilities. For this, some women have used various family strategies to be able to continue integrated into the work of the productive unit. These strategies allow women to combine the care and education of their children with the farm work, which naturally leads to situations in which women encourage the continuation of the operation across generations.

**Conclusions**

In addition to categorizing women’s roles on livestock farms as principal decision-maker, collaborator, observer, this study reflects that the category of “collaborator” is the most frequent. However, in agricultural statistics, the importance of the collaborator role is almost nil. We see two potential explanations for this. First, is the lack of specific questions in the agricultural censuses regarding the contribution that women make to the economic development of farms. Second, the lack of awareness that women have the same rights with respect to men.

The specifics of livestock farming reveal key aspects of women’s work. First, the overlapping of the productive and reproductive spheres make it difficult to distinguish the activities that women carry out in both spaces, which makes it difficult for their families and society in general to recognize their productive role. Second, a system of values and androcentric culture relegates women in the participation of work and decision-making. However, several women developed strategies (work and family coordination) that allow them to be involved in livestock tasks, demonstrating their skills for rural work and farm performance. Others prefer to develop in areas in which men do not show exclusive ability, such as farm business accounting, which gives them the opportunity to be involved with the operation and management of the operation, and thus obtain decision power.

Changes in the organization of work occur slowly. One challenge is that the dual role of family member/caregiver and farm worker makes it difficult for women to obtain remuneration for their participation in work. Additionally, the isolated conditions of the rural environment do not facilitate interaction with other women, which would provide validation/affirmation of their work and increased self-esteem.

**References**


Revitalizing Pastoral Calendars: Snowcover, Seasonal Migration, and Pastoral Decisions from Alai Valley of Kyrgyzstan

Kaziev, Daler.
Graduate Research Assistant, Department of Natural Resources (DNR), Cornell University.

Key words: pastoral calendars, seasonal migration, the Alai Valley, Kyrgyzstan

Abstract
Herding practices among semi-settled agropastoral communities in the Pamir-Alai Mountains of Central Asia are subject to seasonal variations, making climate change adaptation urgent. Livestock keeping is an essential part of the local economy in the Alai Valley of Kyrgyzstan. Focusing on collaborative efforts to develop traditional ecological calendars in the village of Sary-Mogol, Alai valley, Kyrgyzstan, this study seeks to demonstrate the relationship between snow and herding practices. There are four distinct seasonal migration patterns such as *baarloo* spring, *jailoo* summering, *kyzdoo* autumn and *kyshtoo* wintering. The relationship between these migration patterns and biophysical events such as snow accumulation (fall), snow cover (winter) and snowmelt (spring) and snow free (summer) has not been examined, yet these relationships are critical to anticipating climate change impacts on seasonal decisions of the local herders. Based on qualitative analysis of forty semi-structured interviews among herders and farmers in Sary-Mogol village over three field seasons, we developed a pastoral calendar for the community. Traditional ecological calendars are a type of place-based knowledge about the cycle of repeated ecological events (biophysical cues) that can be tracked to time livelihood activities. Our results show that snow accumulation, snow cover, snowmelt and snow free periods are essential cues to anticipate snow cover change and seasonal herding decisions. The revitalized ecological calendar is an example of building anticipatory capacity in response to climatic changes at the village level. Therefore, similar calendars could be revitalized for other agropastoral communities in specific places and climatic conditions.

Introduction
In the Pamir Mountains of Tajikistan, Afghanistan, and China, various traditional and ecological calendars were re-discovered more than a decade ago (Kassam et al., 2011). Such calendars include repeating ecological events, like the flowering of various plants, the ripening of fruit trees, the arrival of specific birds, emergence of insects, and seasonal festivals (Kassam, 2011). Based on these recurring seasonal events, people time their seasonal activities such harvesting, fishing, and herding livestock. As climate change makes it difficult for agropastoral communities to time their seasonal decisions and these calendars could provide insights on how to anticipate climate variation at local scale (Kassam et al., 2018). As part of an international transdisciplinary research project, this study focuses on agropastoral calendars from the Alai Valley of Kyrgyzstan (Kassam et al., 2018). Building on previous studies on pastoral activities, seasonal mobility, and herding decisions in the Alai Valley (Shirasaka et al., 2016; Watanabe and Shirasaka 2018) this study asks how farmers use their knowledge of ecological calendars in pastoral decision-making including the timing of seasonal movements, sheep breeding, lambing, and food storing. As a result, biophysical events like snow accumulation (fall), snow cover (winter) and snowmelt (spring) and snow free (summer) are discussed in relation to the seasonal patterns such as *baarloo* spring, *jailoo* summering, *kyshtoo* wintering, and autumn *kyzdoo*. Also, the importance of pastoral calendar for timing of sheep breeding, and food security has been discussed.

Methods
This research entailed three phases in an iterative, participatory approach: 1) a seasonal round workshop, 2) semi-structured interviews, and 3) community validation. In this international, collaborative and transdisciplinary research,
the knowledge in ecological calendars is co-generated in collaboration of a community of inquiry (scientists of diverse backgrounds) with a community of social practice (farmers, herders, hunters, and fishers) (Kassam et al., 2018). The first phase of developing ecological calendars in the Alai Valley began in July 2016 with a Seasonal Round Workshop (SRW). 24 people participated in the workshop. We learned about local seasons, biophysical indicators that mark these seasons, animal life cycles, plant life cycles, and pastoral decisions. In phase two (July 2017), we carried out semi-structured interviews among 39 people, 19 male, and 20 women to understand knowledge related to pastoral practices and their relationship to biophysical variables like snow cover changes. The questions were designed considering the social-cultural context, particularly addressing the pastoral calendar from Alai Valley. Based on analysis of interviews, a poster type of calendar was prepared containing Gregorian month names, ecological indicators (birds, plants, and mammals), special local seasons corresponding or correlating with weather events, and human activities (crop planting and livestock herding activities). The third phase of the research was validation (July 2018). In this phase, we cross-checked the validity of the poster calendar with the community in a Validation Workshop (VW) in Kyrgyzstan. We asked the community if the poster with key phenological cues were correct concerning their livelihood activities. This collaborative and participatory approach allowed us to introduce new changes and to correct errors in the draft of the seasonal calendar.

Results
There are four distinct seasonal migration patterns known as baarloo spring, summering jailoo, autumn kyzdoo, and wintering kyshtoo (Watanabe and Shirasaka 2018; Shirasaka and Watanabe 2019). These four seasonal migration patterns are practiced in the village of Sary-Mogol, but with conceptual, linguistic and ecological meanings. In other words, the four seasonal migrations are habitat and climate dependent.

Koldo-karoo (November to April) is the first practice in Sary-Mogol and refers to hand feeding livestock in the village where there is no access to pastures due to snow. In the past, the pastures around Sary-Mogol were only used during the summer jailoo period. In winter, no one would remain in the Alai Valley. The practice of koldo-karoo began in the early Soviet period as local tribes were forced to settle in a place with long snow cover and herders’ mobility was restricted, especially in the winter. In this way, due to sedentarization, hand feeding livestock in the village replaced the traditional wintering season. In other words, hand feeding livestock in the village replaced seasonal kyshtoo wintering station. The period of hand feeding livestock in the village, however, depends on the snow cover period. The arrival of snowfall in November (snow cover shifts) prevents animals from grazing nearby by the village. Therefore, the animals are sheltered and hand-fed in the home shelters until the snow disappears in April.

Second, as the snow disappears in spring (depending on snowmelt period), the villagers herd the livestock called kezuu in nearby pastures around the village in barloo spring herding season. Some descriptive terms that characterize the snowmelt events include guur-tyshty (ice melt along the rivers), ala-telek (appearance of white and black snow patterns in the fields), and sary-kar (the arrival of last yellow-snow). White and black snow patterns determine the departure of winter, and arrival of spring, serving as vital cues in the seasonal calendar of pastoralists in Sary-Mogol village. That is when villagers temporarily herd livestock around the village taking voluntary shifts novad (Watanabe and Shirasaka 2016). The term novad simply refers to herding method in which herders from different households take voluntary shifts to herd community livestock (Watanabe and Shirasaka 2016) in the period of snowmelt in spring and accumulation of snow in fall. The notion kezuu literally means to graze the livestock around the fixed area or village. Again, this practice emerged in response to sedentarization. In the past, with the melt of snow in the summer pastures of Alai Valley, herders would migrate to baarloo spring seasonal pastures (Watanabe and Shirasaka 2018; Shirasaka and Watanabe 2019). That is not the case in Sary-Mogol today because of sedentarization and late snowmelt in the spring pastures. As snowfall accumulates between October and November and snow melts in April and May, herding livestock around the fixed area (village) is practiced twice a year in spring and fall.

Third, jailoo is a summer pasture season (Shirasaka et al., 2014; Shirasaka and Watanabe 2019). Moving to the jailoo summer pasture begins in late May and early June, depending on seasonal cues such as snow free period. During the summer kok chykty grass should emerge, kok kubuu livestock should graze the newly emerged grass, and livestock should eat enough fresh grass. Community members observed that livestock become picky and refuse to consume reserved fodder, especially when fresh grass emerges. Farmers move to the summer pastures by observing snow melts in the pastures that are located at the south range (Zaalai Range)
and north (Alai Range). If herders remain in the village, practicing the village-based herding becomes impossible, newly emerged barley is under the risk of being eaten by livestock. In some part of the Alai Valley, local herders move from 2500 m.a.s.l elevation up to 3500 m.a.s.l (Liu and Watanabe 2014; 2016) while the herders in settled villagers in the Alai Valley migrate less than 100 km, especially in Sary-Mogul village. As studies show, the herders in the Alai Valley do not migrate long-distance during the summer pasture season (Watanabe and Shirasaka 2016). Also, with the emergence of vegetations, the milking season begins. This means that people will have \textit{ak-chykty} (milking products) from April to October. Dairy products are processed and stored in summer and are consumed until the next spring, especially in April and May. This period is known as the long yellow \textit{uzun sary} (starvation period). Thus, from April to September, the farmers take advantage of the short growing season.

In early September when the \textit{jailoo} season ends, the pastoralists return to the village with their flocks to continue \textit{kezu} or \textit{novad} practice, which is the fourth herding practice (late August to mid-September). The arrival of autumn is associated with the changing behaviors of livestock. In late August, livestock do not graze in the higher pasture lands, and they keep descending to lower elevation fields as a result of declining temperatures. Due to cold, the livestock start to leave higher pastures even if there is grass available. This livestock behavior is called \textit{otko-kachat}. An unexpected sudden frost could threaten the sheep in late August to mid-September. However, not everybody returns to the village when these events occur. In Sary-Mogol, some farmers have houses near summer pastures where they stay year-around.

The pastoral calendar can be useful to time sheep breeding, but it is hard to predict when temperatures will change in spring. As the winter approaches in October and November, the herders time domestic sheep breeding to plan for \textit{baargi tol kiret} (spring lambing) in March and April. Currently, October seems to be the best time to breed sheep, because farmers have to be certain that lambing in spring takes place when temperatures are warmer. What we have learned is that the villagers count 5.5 and 6 months when breeding sheep. During October or November, the farmers breed sheep and goats, known as \textit{kochkor koshylat} (the male and female sheep are put together). Once the herders return from the summer pasture, as temperature drops, sheep breeding begins. We were told that, the primary threat in autumn is \textit{kyrgyz}, a sudden frost that could kill both small livestock as well as damage potatoes. However, in Sary-Mogol, sheep breeding is not constrained by environmental variables in fall. Five months after breeding sheep \textit{kochkor koshylat}, in October, \textit{baargi tol kiret} (spring lambing) takes place around March or April. Although some farmers undertake \textit{kysky tol} (winter lambing), during January and February, this is not commonly preferred. Cold temperatures during winter, the fear of exhausting fodder reserves, and uncertainty of shifting seasons spring (shifting times of snow melt), are the primary concerns. If the winter temperature is too cold, the young lambs might not survive during January.

Fodder production plays an essential role in securing livestock throughout the long winter and spring in the Alai Valley. During the short growing season, people harvest barley, Common Sainfoin (\textit{Onobrychis}), and potatoes in addition to fodder grasses (\textit{Leymus secalinus}, \textit{Aceae} and \textit{Atipa orientalis}). These fodder grass used to feed livestock during the 6-7-month winter period. As the Alai Valley receives too much snow, people handfeed livestock in the village. The winter lambing demands farmers’ attention and requires much fodder. Having some fodder remaining for spring is crucial, because situations with snow in spring are uncertain. The key, therefore, is to time livestock breeding to take advantage of warm temperatures in spring, especially in April. Sometimes, stored fodder may not be enough to overcome the winter if snow melt shifts or extends until June. Hence, the pastoral calendar reveals important insights and relationships of pastoral decision with biophysical cues.

**Discussion and Conclusion**

Within the framework of the Ecological Calendar and Climate Change Adaptation in the Pamirs, this research studied pastoral calendars from the Alai Valley of Kyrgyzstan. Building on existing literature on pastoral studies in the Alai Valley, this study examines the relationship between biophysical indicators such as snow accumulation, snow cover and snow melt with seasonal and livestock migration patterns. Because people in the Alai Valley practice and subsist on pastures, this study examined how herders make seasonal decisions about livestock migration in spring, summer, fall and winter. Despite a history of forced sedentarization, Sary-Mogol pastoralists still practice four distinct seasonal migrations that are not outside of snow related changes. Based on the community workshop in 2016, semi-structured interviews in 2017, and community validation in 2018, and ecological calendars, this study revealed that these four distinct seasonal migration patterns are driven by snow accumulation (fall), snow cover (winter) and snowmelt (spring) and...
snow free (summer). In other words, snow-cover period refers to hand feeding in the village during the winter. Snow melt period in spring refers to village-based herding. Snow-free period refers to the summer pasture season. Snow accumulation period in fall refers to village-based herding in fall. Because the season indicators are subject to variation and change with climate, the study of pastoral calendars provides potential anticipation of biophysical cues and livestock related decisions.

Acknowledgements
This study was supported by Belmont Forum funded international and transdisciplinary research project “Ecological Calendar and Climate Change Adaptation in the Pamirs” (ECCAP). I would like to acknowledge Dr. Maria Fernandez-Gimenez for providing academic support and review.

References


Socially differentiation in (agro)pastoral climate change adaptation: Intersectional perspectives on socio-technical change in Kenya and Burkina Faso

Todd Crane, Lisa Nebié and Teresiah Ng’ang’a
ILRI, CRAF and University of Nairobi

Introduction
Due to the climate sensitive nature of cropping and livestock keeping, climate change adaptation has emerged as a central issue in agricultural/rural development. Even development interventions that are not focused on climate change adaptation are increasingly called on to be sensitive to the implications of climate change impacts. However, many approaches to agricultural adaptation to climate change remain highly technocentric, for example relying on measures of drought resistance and productivity to indicate adaptiveness without consideration of how a new practice/technology will move through and be shaped by social spaces of household labor, market access, land use decision making, cultural values, etc. (Crane et al., 2011).

Critical social science work, especially from development anthropology and political ecology, has outlined the contours of socially differentiated effects of agricultural development interventions for decades. The integration of these considerations into intervention planning has been slow and uneven. The emerging discourse of climate smart agriculture (CSA) is no exception. Instead, there is often an underlying, if unstated, assumption that rural society is relatively homogenous, that the promotion and implementation of CSA practices is an apolitical process. This is institutionalized in that the key measures of success in CSA tend to focus on system level outcomes such as resilience/adaptation (maintenance of productivity under climate stress), reduction of GHG emission intensities, and food security (Thornton et al., 2018). In this system-based evaluative framework, there is little explicit space for addressing how the promotion and adoption of CSA practices may - like so many well-meaning “technical” agricultural interventions in the past - produce an uneven social distribution of benefits. Furthermore, the emergent changes in social organization through technical changes are often treated as an instrumental aspect of achieving system level outcomes, rather than as outcomes of interest in and of themselves. However, like any changes in technical livelihood practices, climate change adaptation is a fundamentally social process. As such, social science research into adaptation requires attention to how adaptation practices are socially differentiated, in terms of how they develop, how they are implemented, and how benefits are distributed as the practices are institutionalized.

The objective of this report is to synthesize research from within the Local Governance and Adaptation to Climate Change (LGACC) project that analyzes how mechanisms of social differentiation affect climate change adaptation in pastoral societies that are transitioning toward more sedentary mixed agro-pastoralism. Rather than recounting the details of each case study, the purpose of this report is to distil the key lessons learned from the case studies. Starting with three key dimensions of social differentiation - gender, age and ethnicity - the research has analyzed how these factors affect the strategies that are available to and accessed by people. This has been done through case studies of a small set of emerging adaptation practices in each of the field sites, which are analyzed in terms of the social processes through which they emerged and how the practices organize people in their implementation and access to benefits. The ultimate objective is to identify the mechanisms through which these different social categories affect adaptation processes and outcomes.

Dimensions of social differentiation
Gender research has widely emphasized that vulnerability to the impacts of climate change are not necessarily going to be evenly distributed in society (Bryan et al., 2017, Denton 2002, Ravera et al., 2016.). This is because vulnerability is partly a function of the mechanisms by which negative effects are socially distributed. Furthermore, gender research has long highlighted the ways that agricultural development interventions, far from being apolitical or gender neutral, can have substantial implications for gendered access
to production resources, markets and benefits of change, both in positive and negative ways (Ravera et al., 2016, Alston 2013, Tavenner and Crane 2018, Sultana 2018).

Much has been written about the difficulty of youths gaining access to opportunity due to elder men’s retention of control over key productive resources, and this is as relevant to climate change adaptation as other domains. Age can also influence access to social and financial resources, information networks, generational differences in education, varying risk assessment priorities (White 2012, Sumberg et al., 2012). Given the emerging interest in creating better opportunities for youth in agriculture, age is becoming an increasingly important research domain relating to social differentiation in adaptation processes.

Ethnicity is particularly relevant in research on pastoral societies that are transitioning toward more sedentary agro-pastoralism. In both East and West Africa, historical interlinkages between ethnic identity and pastoral lifestyles and values can influence culturally conditioned criteria by which people evaluate potential adaptation pathways and practices (Crane 2010). The historical trajectory of livelihood strategies also influence access to land, technical knowledge frameworks, which also affects perception and evaluation of potential adaptation practices. The history of the relationships between customarily pastoral ethnic groups and non-pastoral neighbors can also affect access to land, resources and information networks.

Methodology
Following the mandate of the project commissioner, USAID, the LGACC project selected research sites in Burkina Faso and Kenya where communities relied heavily on pastoral commons and had met some relative success in adapting to climate change. For the analysis of social differentiation in climate change adaptation practices, scoping studies were conducted in each site first to catalog the range of relatively new livelihood practices in order to identify socio-technical change dynamics and emerging adaptation practices. This catalog of practices was then evaluated for which practices were most directly responsive to climate stress and whether their implementation occurred within households or in a more collective-community manner. Three practices were selected in each site for deeper analysis, with deliberate inclusion of at least one practice that required collective action and one practice that was implemented within households.

Using qualitative data collection methods of interviews, focused group discussions and participant observation, each of the selected practices was then analyzed in terms of the social processes of its evolution and implementation within the research sites, situating the practices both historically and socially. Adapting an innovations systems approach (See Triomphe et al 2013), particular attention was given to how specific actors drew on various resources (material, financial, social, informational, etc.) in the process of developing or introducing the new practice. Furthermore, the practices were analyzed in terms of how people organize to implement them, with particular attention to the socio-economic profiles of the actors who were (and weren’t) engaging in the practice, mechanisms of accessing and using the resources necessary for the practice, and distribution of labor and benefits within households.

This approach to analyzing the various adaptation practices allows us to use empirical cases to identify how and where gender, wealth, age and ethnicity have played roles in the social distribution of adaptation practices. Due to its case study-based approach, this research is not designed for generalization of patterns. Instead, it is meant to identify the mechanisms by which each of these social variables shape peoples’ constraints and opportunities.

Synthesis of results
In Burkina Faso, the two of the three emerging adaptation practices centered around fodder: harvest of wild grasses and cultivation of fodder species both for conservation of fodder for feeding to animals over the dry season. The third emerging practice addressed the governance of the pastoral zone itself, particularly the enforcement of its boundaries. In Kenya, the three emerging adaptations practices cover a variety practices at different scales: the original establishment of the Il Ngwesi Conservancy itself, the private and collective fodder cultivation, and species diversification into dairy goats.

Gender
In both Kenya and Burkina Faso, gender was found to be a key variable in terms of distribution of household labor in new adaptation practices, as well as access to information networks. The integration of any new practices into a household economic strategy almost always implies reorganizing labor roles.

Both the Sondré Est pastoral zone and the Il Ngwesi conservancy were established in direct response to drought impacts in the 1980s, which devastated pastoral livelihoods in both East and West Africa and widely precipitated
sedenatarization and greater territorialization of previously transhumant herders. In both areas, women have had little to no explicit role in the large-scale collective processes of establishing, maintaining and governing their respective territories.

The transition from pastoralists to agro-pastoralists in Burkina Faso has necessitated changes in household gender labor roles. Customarily, the primary gender roles have been for men look after animals and women market milk. Although men customarily own and herd cows, milk is women’s domain. Men also engage in cultivation in circumstances where that is needed. There have customarily been strong cultural norms against pastoral Fulbé women engaging in cultivation or manual labor of any sort, whether field crops or market gardens (Crane 2010). In Sondré Est, Fulbé women still sell milk in neighboring Mossi villages, but they have been taking up labor roles in transport of cut fodder. Increasingly sedentary lifestyles are furthermore contributing to relaxation of cultural taboos against Fulbé women engaging in manual labor. As livelihoods become more reliant on intensified management practices, rather than extensive herding, women’s manual labor becomes an important component of household economic productivity. This has led to women starting to do manual labor in cultivation of food crops or animal fodder. The pressure for Fulbé women to engage in manual labor is compounded if their husbands and/or sons go on transhumance with their herds, because the absence of male labor in a household shifts the labor burden onto women. Access to stored fodder in the dry season stretches milk productivity, the sale of which remains a squarely female domain, and thus contributes directly women’s economic benefit and household food security.

In Kenya, customary gender roles have likewise shaped engagement in and access to adaptation practices. The conversion of Il Ngwesi from a group ranch to tourist destination led to a diaspora of former residents to a variety of locales around the edge of the conservancy. For those women who now live in towns, opportunities to engage in small-scale commerce or open restaurants have opened up a new range of livelihood opportunities in circumstances where that is needed. There have customarily been strong cultural norms against pastoral Fulbé women engaging in cultivation or manual labor of any sort, whether field crops or market gardens (Crane 2010). In Sondré Est, Fulbé women still sell milk in neighboring Mossi villages, but they have been taking up labor roles in transport of cut fodder. Increasingly sedentary lifestyles are furthermore contributing to relaxation of cultural taboos against Fulbé women engaging in manual labor. As livelihoods become more reliant on intensified management practices, rather than extensive herding, women’s manual labor becomes an important component of household economic productivity. This has led to women starting to do manual labor in cultivation of food crops or animal fodder. The pressure for Fulbé women to engage in manual labor is compounded if their husbands and/or sons go on transhumance with their herds, because the absence of male labor in a household shifts the labor burden onto women. Access to stored fodder in the dry season stretches milk productivity, the sale of which remains a squarely female domain, and thus contributes directly women’s economic benefit and household food security.

In Kenya, customary gender roles have likewise shaped engagement in and access to adaptation practices. The conversion of Il Ngwesi from a group ranch to tourist destination led to a diaspora of former residents to a variety of locales around the edge of the conservancy. For those women who now live in towns, opportunities to engage in small-scale commerce or open restaurants have opened up a new range of livelihood opportunities in circumstances where that had previously not been possible.

Fodder cultivation and managed grazing are two key adaptation practices that are being implemented in Il Ngwesi. Fodder cultivation has been implemented by individual households as well as by collectivities, including both by the conservancy administration as well as groups of independent self-organizing households. In all cases, the strategic planning and organizing of materials and networks necessary for fodder cultivation has been the domain of men, as heads of households and heads of the community administrative apparatus. While women have not had leadership roles in the planning of fodder cultivation, this is not to say that they haven’t had any role or benefits. Women are expected to maintain and repair fencing around any household cultivation plots, which are occasionally damaged by elephants. However, this labor burden also comes with access to benefits. Women are typically responsible for looking after weak or very young animals who aren’t able to go out grazing with the herd. This implies cutting of wild grasses to hand feed to the weak animals. The availability of stored fodder grasses thus reduces women’s daily work load.

Herding cattle is customarily a squarely masculine activity. This includes going on long-distance transhumance as well as day-to-day following of the herds. The decision to engage in rotational grazing within the production-oriented zones in the Il Ngwesi Conservancy as well as the implementation of rotational grazing practices is done by men. However, rotational grazing makes it possible for more male herders to stay in the area rather than migrating long distances with their herds, a migration which presently doesn’t often involve full families due to sedentarization. Because milk customarily belongs to women, diminishing migration means that women and children have better access to milk for consumption or for sale.

Age

Age was found to have a variety of effects on how adaptation practices were adopted or implemented. In Il Ngwesi, the eldest male heads of household were generally disinclined toward the adoption of new practices such as rotational grazing and fodder cultivation. Instead, they exhibited and expressed preference for the more familiar customary practices of migration. Middle aged men (~40-60) were typically the most involved in adoption of rotational grazing and fodder cultivation. Instead, they exhibited and expressed preference for the more familiar customary practices of migration. Middle aged men (~40-60) were typically the most involved in adoption of rotational grazing and fodder cultivation. Generally speaking, they are young enough to be open to change, but old enough to control or draw upon sufficient financial, knowledge, social and material resources to effectively pursue new practices. Male youth (~20-40) perspectives on adoption of adaptation practices varied widely. Customarily, Maasai male youth are known as morans, or warriors, who focus their energies on herding cattle in the bush and are as an age set, somewhat outside of some social boundaries. However, adaptations oriented toward intensification or cultivation are anathema to moran identity, which is customarily
closely intertwined with extensive pastoral practices and lifestyle. Knowing that their elders had lived the culturally valorized moran lifestyle, youth are often unresponsive to elders’ entreaties to change away from extensive pastoralism, a proposition which they find robs them of their patrimony as Maasai morans. However, beyond such identity arguments, young men do not control substantial amounts of resources – including land and livestock – making pursuit of innovative adaptation practices particularly challenging, unless they get out of basic production altogether. However, this difficult for many young men, because of the relatively low education levels, a fact which is itself slowly changing.

As mentioned in the gender sub-section, while women in Il Ngwesi, regardless of age, have some role and benefit in the implementation of some adaptation practices, they have little social power for strategic planning or use of resources unless they are outside of the pastoral economy. Older married women may have some degree of informal leverage in intrahousehold negotiations around livelihood practices, they have little structural power. Young women, usually recently married and relocated to their husbands’ family and community, have very little social leverage for pursuing new adaptation strategies.

In Burkina Faso, elder and middle-aged men were heavily implicated in policing the boundaries of the Sondré Est pastoral zone, forming the heart of the Management Committee (COGES, short for Comité de Gestion). COGES is mandated with protecting Sondré Est against any inappropriate incursions, primarily by agriculturalists living around the pastoral zone and by migratory herders from outside of the area. This is an important part of the pastoral zone as an adaptation strategy, because residents’ vulnerability to climate stress would be elevated if the integrity of their resource base is not maintained. While young men often have responsibilities to herd animals within the zone, they do not take an active role in policing it. Elders characterize young men (~20+), who are starting to assert their independence, as generally being unresponsive to their authority.

Fodder cultivation, harvest and conservation, important intensifications in pastoral production, are primarily the responsibility of male heads of households, but they draw substantially on male children’s labor. Adult women and girls support these activities by bringing food and water to the fields, which are often distant from households. Women and girls may also help in transport of the harvest back to the households, which is most often done by transporting bundles on the tops of their heads, as there are few carts available in the area.

Older women in Sondré Est report significant and increasing contributions to adaptation practices relating to fodder harvesting and agriculture in general, going against cultural norms that Fulbé women shouldn’t engage in manual labor. However, younger women are described as being more resistant to agricultural activities. While fodder cultivation and harvesting may be materially adaptive, it also represents quite some hard physical work. Young women perceive this hard manual labor and the muscular bodies it creates, as a threat to their cultural ideals of femininity and thus worry that it makes them less attractive as a marriage partner. While older women recognize young women’s concerns, they claim that as younger women mature and establish their own families, the practical material demands of contributing to their families’ wellbeing will eclipse concerns about idealized femininity.

Ethnicity

The study sites in both Kenya and Burkina Faso were ethnically homogenous, focusing on Maasai and Fulbé communities respectively. However, ethnicity is still apparent as a factor that influences the pursuit of adaptation to climate change. Maasai and Fulbé have traditionally been iconic pastoralists of East and West Africa respectively, with cultural norms and values, as well as social organization, in both groups heavily organized around pastoralism as a core reference point. While both cases illustrate the demise of extensive pastoralism as a livelihood practice, they also show how pastoralism maintains a certain continuity in the face of change.

Both Sondré Est and Il Ngwesi were initially established as dedicated pastoral zones for ethnically homogenous communities. Sondré Est was comprised of Fulbé who migrated from northern Burkina Faso to their new home in Southern Burkina in direct response to the devastating droughts of the 1970s and 1980s. This relocation was facilitated by the national government and supported by the village chief of Sondré, who donated the land. Subsequently, development interventions in Sondré Est have been focused around livestock-oriented activities – including intensification of fodder production and wild harvesting (ongoing) and dairy processing (now defunct due to technical maintenance issues) – appealing to Fulbé knowledge, interests and values in livestock-based livelihoods even when becoming agriculturalists could have been a potentially viable adaptation pathway.

The conversion of Il Ngwesi from a group ranch to a nature conservancy stimulated an exodus of a large portion of the population to outside of the conservancy, a diaspora who relocated to...
communities adjacent to Il Ngwesi. Subsequent adaptation strategies have varied significantly depending on where they moved to. Some members of the Il Ngwesi diaspora migrated to an area which was endowed with good soils and irrigation infrastructure for market gardening. Recognizing the opportunity afforded by access to irrigation, they set to learning how to farm, which involves not only hydrology and agronomy, but also marketing. Research participants reported that the learning curve on this was very difficult because not only did the Maasai diaspora not have the knowledge and skills for farming, but they didn’t have the socio-economic networks that enabled them to effectively market their harvest.

Agricultural knowledge and skills can be gained through experience, but they can also be gained by marrying people with needed knowledge and skills. Maasai intermarriage with other ethnicities with more agricultural backgrounds is not a new phenomenon, but field reports from Il Ngwesi indicate that it is being done strategically in response to their new sedentary circumstances. One elderly man tells the story of when he first relocated from the conservancy to a relatively small plot in an agricultural area. His first wife, a Maasai, was unmotivated to convert to an agricultural livelihood and preferred to stay near the grazing zone in the conservancy. Consequently, he chose to take on a second wife, a Kikuyu, who would know how to farm, thus enabling him – through her labor – to capitalize on his new agricultural property. This personal anecdote highlights that knowledge and skills appropriate to specific livelihoods is learned within cultural contexts. Integrating those skills and knowledge into a household strategy can sometimes be more easily achieved through intermarriage than through training or through trial and error.

For Il Ngwesi diaspora who moved or remained in pastoral areas, the most prominent and prevalent adaptation practices continue to be oriented toward supporting livestock keeping. Cultivation of fodder grasses has been taking off in recent years as a way of getting more productivity from the pastoral zones. While this also involves new practices, skills and knowledge, people are motivated to do what they can to support livestock keeping as a central livelihood activity rather than converting to agriculture.

Discussion and Conclusion

Gender, age and ethnicity are three key dimensions of social variability that help explain differentiated patterns of adoption and benefit from climate change adaptation practices. Cultural gender norms prescribe “proper” behavior for men and women, which can shape how they evaluate, pursue and benefit from new practices. Understanding how age affects access to material resources, social standing and knowledge networks will help adaptation efforts account for hierarchies commonly found in agrarian and pastoral communities. Ethnic identity – and all of the norms and values that accompany it – can be an important factor in how people evaluate and pursue various potential adaptation pathways, as well as how a community interacts with other ethnicities around them in landscape level politics.

It needs to be emphasized here that while these dimensions of social differentiation affect people’s behaviors, they do not determine people’s behaviors. Cultural norms relating to gender, age and ethnicity are dynamic and there is always some degree of variability in how closely people adhere to or deviate from them. Rather than being deterministic, cultural norms relating to gender, age and ethnicity are simply frameworks within which individuals assert their own agency. The assertion of agency within dynamic and contested cultural frameworks is a key element of how cultural change occurs, which is particularly important during processes of rapid or extreme change which are often characteristic of climate change adaptation.

Although social variables can have some degree of causality regarding how adaptation processes unfold, they are not static. The pressures that drive and interact with adaptation processes can also contribute to changing social norms and relationships. The increasing adoption of agricultural activities and intensification of livestock keeping practices in both Burkina Faso and Kenya speak to this dynamism, especially as they relate to ethnic ideals of and preferences for extensive pastoralism.

The social differentiation component of the LGACC has examined aspects of gender, age and ethnicity in order to unpack how they act as mechanisms that shape adaptation processes. A next step for this kind of research would be to do a fully intersectional analysis, which would treat gender, age and ethnicity as overlapping and interacting variables instead of independent ones (Thompson-Hall et al., 2016, Djoudi et al., 2016). However, whether intersectional or not, research on social differentiation in pastoral and agricultural communities should be useful in planning and implementing programmatic interventions for climate change adaptation so that they can account for the various dimension of social heterogeneity.
References
Women’s empowerment for demographic issues and conflicts in African pastoralist societies

Cevallos, M.R.¹ and Manzano, P.²,³

¹PhD program in Humanities and Communication, Universitat Oberta de Catalunya, Spain; ²Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, Finland; ³Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, Finland

Key words: women, conflict, pastoralism, demography

Abstract

Widespread conflict is a recurring issue in African pastoralist societies. While its roots are debated, there is a missing link with prevailing poverty among communities and particularly among women. We here apply a gender perspective to establish a hypothesis on the role of women in pastoralist conflicts.

The existing polygynic system establishes a violent frame for pastoralist women, who would be sold at increasingly early ages to provide in turn enough resources for furnishing the dowry needed by their brothers. The control on them would thereby be transferred from their own families to their husband and his family, where they have also to endure competition for resources with other wives. Survival strategies are linked with fertility, as a higher offspring allow women a higher access to power and resources. This has, however, negative individual consequences in terms of personal health and workload, as well as a higher collective burden on reduced per-capita income and increased poverty. The latter is more severe for women, having restricted access to resources and decision-making.

Delivery of formal education is particularly weak among pastoralist societies. It is, however, an empowerment tool that contributes to higher well-being across the community. Firstly, it allows economic diversification and establishment of independent income sources. And secondly, it provides women with the tools to decide on their reproductive health that have consequences on poverty - both at controlling fertility and increasing investment in children’s education. ICT brings here a further possibility to access information not subjected to the control of men in their family, potentially being an important empowerment tool for women and thereby a tool for conflict mitigation or resolution.

Introduction

The arid belt of the Sahel and the Greater Horn of Africa (GHA), where pastoralist societies have traditionally developed, experiences recurring conflict that has gained international attention (De Haan et al., 2016). Conflict between wildlife-based and pastoralist uses, as well as over land ownership, are prevalent in the East, including Tanzania (Manzano and Yamat 2018), Kenya (Fox 2018, Mkutu 2019) or Ethiopia (Feyissa 2014). In the Sahel, conflicts between crop farmers and pastoralists are more dominant, with notable examples from Nigeria (Abbass 2014, Seignobos 2015) but also from other countries ranging from Ghana (Bukari 2017) to Mali (Bagayoko et al. 2017). The weak presence of the State is identified with instability, facilitating terrorist groups (AQMI, Boko Haram; De Haan et al., 2016). While conflict factors has yielded widespread common explanations at the local or the subregional level, they have been contested by a number of evidences. A cross-regional perspective could offer more consistent results for identifying root causes.

Methods and Study Site

We reviewed the available literature explaining conflicts in the Sahelian and GHA regions, using the search strings “pastoralism” and “conflict” combined with relevant geographical tags (country or subregion names). We also built on widely shared papers at relevant pastoralist forums, such as FAO’s Pastoralist Knowledge Hub or CELEP’s mailing list. We applied a test-and-rebate methodology for widespread hypotheses, using a trans-disciplinary approach (Manzano et al., 2021), and we later looked for root explanations in the literature based on gender.
and education, building on previous work by Manzano and Slootweg (2018).

Results
Weaknesses in existing sub-regional explanatory theories

In the Sahel, weak law enforcement in pastoralist areas, which are sparsely populated and have weak State infrastructures, are frequently used as an explanation for prevailing conflict (Seignobos 2015, De Haan et al., 2016). This fails to explain, however, why conflict is present both in drier, more northern locations, and in more humid and southern areas – even if the repression mechanisms are clearly more efficient in the south. It also fails to explain why violence is steadily increasing (Krätli and Toulmin 2020) in spite of the increased deployment of national and international forces in the sub-region.

Climate change is also routinely given as an explanation for dwindling natural resources and increased competition around them both in the Sahel (Abbass 2014, Bagayoko et al 2017) and in the Greater Horn of Africa (Manzano and Yamat 2018). However, such explanations clash with climatic evidence that shows the Sahel is actually re-greening and that rainfall in both regions is increasing due to anthropogenic climate change (Molina-Flores et al., 2020). Misleading factors include erosion due to unsustainable uses that decreases plant productivity in areas of shallow soils (Dardel et al., 2015) and change in rain patterns (Wainwright et al., 2019) to which local management systems may still have not had time to adapt.

Prevalent farmer-herder conflict is increasingly present in West African media, usually with negative depictions of pastoralists (Krätli and Toulmin 2020). Increased competition for land is exacerbating conflict situations in the Sahel (Molina-Flores et al., 2020). But such increase in conflict is happening in the Greater Horn of Africa as well in non-farming areas (Manzano and Yamat 2018, Mkutu 2019). It is related to a general increase in violence and conflictivity, happening also among farmer communities (Krätli and Toulmin 2020). Claims for ancestral bad relationships ignore the mutualistic relationships between farmers and herders, which have depending on each other based on barter or monetary exchanges around manure, milk, meat, hides, transport, grain or use of fallows (Krätli and Toulmin 2020, Molina-Flores et al., 2020).

In the Greater Horn of Africa, claims around competitive land use between conservation and pastoralism ignore the possible coexistence, and even facilitation, of wildlife and domestic herbivores (Schultz and Rubenstein 2016). Interpretations of general livestock increases that would exacerbate competition with wildlife do not match long-term observations when measured in Tropical Livestock Units – a fairer way to compare mixes of livestock species, and which indicates stability of the herd. This is the case both in Kenya (Ogutu et al., 2016, contested by Manzano and Slootweg 2017), and in Tanzania (Veldhuis et al., 2019, contested by Manzano and Yamat 2018). In both cases, the decline of wildlife seems to be rather related to poverty factors than to competition for grazing resources (Manzano and Abella 2020). The same data on stability of herd numbers, and the spread of the community conservancy model (Ogutu et al., 2019, Manzano and Abella 2020) show the weakness of the land grabbing argument to explain the very recent (<15 yr) increases in violence and conflict.

Strength of gender and related demography-poverty effects as an explanatory theory

The explanatory power of gender dynamics is firstly conditioned by increasing poverty. While West Africa is constrained by poor data, especially in Nigeria (Molina-Flores et al., 2020:152) where conflict is becoming more visible in the media (Krätli and Toulmin 2020), the Greater Horn of Africa allows for some case studies with better statistical data. In the Ngorongoro Conservation Area poverty has been continuously increasing since the 1960s and as the local population growth has not been accompanied by income diversification policies or value addition strategies within the livestock sector (Manzano and Yamat 2018). Kenya at large suffers similar problems, with the pastoralist population increasing in numbers but relying on the same economic base, i.e., the same livestock herd (Manzano and Abella 2020). A useful indicator of the increased poverty among pastoralist communities is the balance between goats/sheep and cattle – an increase in sheep/goat proportion shows cash-oriented economic strategies motivated by short-term needs.

Polygamous marriages are a cross-cutting characteristic of the increasingly violent social landscapes of the Sahel and Greater Horn of Africa. Such polygynic systems exacerbate the poverty-driven violent frustration of unaffordable dowry (Hudson and Matfess 2017) – a prevalent system in the whole continent. The violent frame experienced by women starts with the dowry

---

2 This link with population growth departs from misidentified neo-Malthusian perspectives, as in Weld-emichel et al. 2019. It is not about growth per se, but about providing growing income sources for growing populations.
transaction itself, as they become a good to be sold in order to mitigate the poverty at their parental household and to cover the dowry expenses of the household’s sons. The poorer the household, the more urgent is the need to put brides in the market, so women will marry at an earlier age. Because of the increasing poverty-mediated inequalities, as observed e.g. in the Ngorongoro Conservation Area (Manzano and Yamat 2018), men with higher economic capacity – who are usually older, because of more time available to increase capital – will grab more spouses, leaving a big collective of young men that are unmarried and frustrated, and prone to engage in non-legal economic activities such as cattle rustling (Gaskell et al., 2018, Hudson and Matfess 2017), or in abducting women (Hudson and Matfess 2017). This is a powerful explanatory factor of the increased violence in the Sahel and Greater Horn of Africa, but which is almost regularly overseen. The violent frame does not stop at the young population, but continues within the new, polygynous household, where wives compete and engage in harassing behaviors towards co-wives and children (Geary et al., 2014). In such a setting, the placement of the women in the marriage hierarchy is a very important factor, with high fertility rate being a key factor to access power and to gain from a preferential access of resources for her and her children (Madhavan 2001).

The psychological and often physical burden both to mothers and to their children, irrespective of their sex, becomes clear. A derived heightened fertility rate arises from the early access of women into marriage, which extends their fertile years, and the competitive factors which stimulate a higher fertility at the individual level. Such high fertility rates have, however, a collective burden, especially if the resource base is fix as in the case of pastoralism-based societies that do not have income diversification opportunities. Women bear the severest consequences: an increasingly unequal society undermines their access to resources even further, and inequality also cuts any avenues into decision-making, deepening patriarchal structures.

**Discussion**

Conflict in the Sahel and the Greater Horn of Africa is routinely explained by a deterioration of the natural resource base or by competition among ethnic groups. However, we have identified here the gender inequalities and the disempowerment of women in increasingly unequal polygamous marriages as a powerful explanatory root cause. While the way to disempowerment is clear, the way to empowerment is also well defined. Formal education has a multidimensional transformative effect, allowing for diversification of income but also for creating new opportunities within a sector – the livestock sector in our case. Pastoralists in general and women in particular are, unfortunately, subjected to particularly weak delivery of education services (Pearce 2009), in countries where access to education is already weak (de Haan et al., 2016, Manzano and Yamat 2018).

Violence is likely to be greatly reduced through improved education delivery by a wide array of factors. Firstly, higher education levels imply more and better income sources, and less inequality. The inequality tensions among young single men that tend to lead to violence are improved through diversification and derived improvement of income, to which educated men are more much more prone (Bruyere et al 2018). Reducing inequality in the access to dowry seems to have been key in Saudi Arabia’s strategy to mitigate social tensions (Hudson and Matfess 2017). Higher education in women translates into a higher incorporation into workforce, meaning also reduced inequality and poverty (Canning et al., 2015). Secondly, economically empowered women are much more independent (Flintan 2009), therefore being less vulnerable to violence and much less likely to reject entering unequal settings such as polygynous marriages. A higher independence translates into more control on reproductive health, which implies decisions towards less fertility (Upadhyay et al., 2014) and a higher investment dedicated to educating each child (Canning et al., 2015).

The scope for Information and Communications Technology (ICT) to bring additional opportunities is becoming a reality. Pastoralists can benefit from such tools for education to reach remote areas (Swift and Krätli 2010). ICT is expanding across farmer settings in Africa with the increased use of mobile phones (Abdulai et al., 2019). A very interesting avenue to explore is the role of such technology for accessing information independently. Support and counseling networks established in Kenya are increasingly providing psychological support anonymously, helping women to manage situations of violence or forceful conception within the marriage. They also provide tools to escape undesired settings or strategies to mitigate or resolve conflicts within the household. A characterization of such arising networks is a promising research avenue that can also clarify how digital literacy can become a tool to mitigate widespread societal violence that originates in deep gender inequalities at the household level.
Acknowledgements
Pablo Manzano was supported by HELSUS and the International Union of Biological Sciences (IUBS).

References


THEME 7. CAPACITY, INSTITUTIONS AND INNOVATIONS FOR SUSTAINABLE DEVELOPMENT IN RANGELANDS/GRASSLANDS

Topic: Re-envisioning Rangelands in the 21st Century: Overcoming the Marginalization Narrative
Creating win-win policies for sustainable pastoralism

Huber-Sannwald, E.1, Martinez-Tagüeña, N2, Espejel, I.3, Reyes Gómez, V.M.4, Lucatello, S.4, Lauterio Martínez, C.L.1, Arredondo T.1

1Instituto Potosino de Investigación Científica y Tecnológica; 2CONACYT-Consorcio de Investigación, Innovación y Desarrollo para las Zonas Áridas-IPICYT; 3Universidad Autónoma de Baja California; 4Instituto de Ecología A.C.; 4Instituto de Investigaciones Dr. José María Luis Mora

Keywords: government programs, rangeland socio-ecological systems, resilience of rangeland multifunctionality

Abstract

Institutional, political and market changes have introduced highly unpredictable conditions for rangeland pastoralists world-wide, constantly coupling and decoupling ecology, culture, economics, and politics. While public policy increasingly attends to pastoralist livelihoods and tenure rights, lack of system-specific considerations may lead to social-ecological mismatches and ineffectiveness. In Mexico, most drylands are communal rangelands (ejidos). Most drylands are currently used for livestock production, often at the expense of native grass species and the provision of a broad set of ecosystem goods and services for the wellbeing of local dwellers and the global community at large. Neoliberal policies triggered, among other changes, changes in land tenure in ejido land. The 1992 reform of the Mexican Constitution launched a wave of privatization of communal land with short- and long-term consequences on the multifunctionality of pastoralist landscapes and implications for the values of all ecosystem service categories. While most ejidos maintain some communal use areas for risk avoidance, some ejidatarios benefit from the titling process both to enter rental markets and to acquire small-parcelled pastures for cattle production. However, parcelling out and fencing in of small grazing plots, and the establishment of water ponds in former communal lands, have been leading to severe fragmentation of rangeland landscapes with consequences on local and regional hydrology, rangeland ecological function, adaptive capacity and system resilience. We show how newfound interests in maintaining multifunctional landscapes can be fostered by transdisciplinary partnerships including local communities and representatives of the public and private sector. These partnerships do not only strengthen communal efforts but also help rangeland social-ecological systems provide multiple ecosystem goods and services, whose valuation eventually stimulates the generation and maintenance of highly diverse multifunctional rangeland landscapes. We conclude that recognizing the importance of multiple knowledge systems associated with particular socio-ecological rangeland systems may naturally lead to adaptive management and thereby enhance local food security, pastoralist livelihoods, and rural sustainability.

Introduction

In Mexico over 50% of the terrestrial surface is covered by drylands, whose principle use has been extensive livestock production in diverse grassland and shrubland rangeland systems (Arredondo and Huber-Sannwald 2011). Twenty-five percent of Mexico’s human population inhabits these lands. Most Mexican drylands are communal rangelands (ejidos) characterized by diverse desert scrub landscapes, while private ranchers own and manage the more productive semi-arid grasslands. Historical transformations in the land tenure system and land ownership laws have profoundly shaped the socio-political landscape of Mexican rangelands. In the 1980s and 1990s, emerging neoliberal policies replaced social welfare programs such that the state was no longer regarded as acting in the public interest but in the private interest of a few (Guerrero Rodríguez 2013). New adverse (one-size-fits-all) government programs promoted rain-fed agriculture for staple food production (PROCAMPO, a Support Program to Agriculture, acronym in Spanish, was an income subsidy program for those producers of corn and other base crops who were likely to suffer losses to trade-related competition, Pastor and Wise (1997)), causing massive land cover change and ultimately land abandonment due
to the lack of reliable water sources. PROGAN was a government compensation program that supported sustainable animal and livestock production and livestock planning. In return for this subsidy ranchers had to protect, reforest, or restore degraded land, establish animal corridors, among other actions. As a consequence of the lack of access to plant material and restoration training, peasants increased livestock production without complying to the subsidy requirements. The National Commission of Forestry (CONAFOR) promotes diverse soil conservation programs nation-wide, however their efficacy in reducing land degradation and restoring ecosystem goods and services for human-wellbeing is unknown, as these programs do not include monitoring and evaluation protocols. One study that examined the impact of these programs on a large number of sites in communal lands demonstrated that after four years of soil conservation measures, key soil indicators showed deficiencies in soil properties related to productivity and hydrological function in comparison to control sites (Cotler et al., 2013). Also, social indicators did not reflect successful outcomes. While the short-term economic stimuli encouraged broad participation, the lack of consideration of non-financial interests ultimately lead to a low adoption and replication of these measures by local farmers. In 1992, changes in the Mexican Constitution (Art. 27) opened the communal (ejido) lands to privatization and sale, creating land markets and permitting the selling and leasing of formerly collectively held land and natural resources. The new policy (PROCEDE) triggered profound transformations in the socio-political structure of the Mexican agrarian sector, greatly affecting Mexican rangeland socio-ecological systems. This incentive policy was intended to benefit private farmers primarily, so they could enter the land market and expand their properties. In theory, small-holders could diversify livelihoods. However, the parceling of land reduced water access, leading to the installation of earthen ponds as watering points, creating forage limitations. Ultimately, the decline in communal land and increasingly limited access to grazing land reduced mobility, increased local grazing pressure, and ultimately led to rising land degradation and social conflict (Coppock et al., 2017).

In summary, while sustainability appeared in the Mexican legal framework in 1988 with the General Law for Ecological Equilibrium and Environmental Protection, the Mexican sectoral institutional framework has hindered the effective implementation of the 21 environmental laws (Martinez Peña et al., 2011). Additionally, institutional capacity has been concentrated in federal and state decision-makers thereby promoting one-size-fits-all government programs. These programs enhance productivity, competitiveness and profitability at the cost of slow variables that control the resilience of rangeland systems to climate variability and other non-linear and uncertain dynamics of complex rangeland systems (Huber-Sannwald et al., 2012). While cross-scale interactions greatly affect local rangeland systems, federal workers recognize that inherent, idiosyncratic features at regional and local scales are frequently ignored, and they acknowledge poor flexibility in changing the governance and institutional logic/capacity (Martínez Peña, 2012). While Mexican environmental laws mentions the importance of local knowledge, there is a strong emphasis on technology transfer to local farmer communities. These policy and legislative contexts have contributed greatly to the homogenization of Mexican dryland rangeland landscapes, and thus ignored and reduced their multifunctionality.

The multifunctional social-ecological nature of Mexican rangelands

The high diversity in orographic, edaphic, and climatic factors has contributed to the great diversity of grassland and desert scrub communities in Mexico, which collectively support a larger number of endemic species than Mexico’s tropical forests (CONABIO 2010). These diverse landscape characteristics have allowed the evolution and expansion of highly diverse livestock production systems, hence the inherent natural heterogeneity of these rangeland landscapes is often blurred by local livestock management practices (Tenza et al., 2017, Martinez Tagüeña et al., 2020). Further, long-term legacy effects of past climate and management affects the resilience of these systems to climate change and to other disturbance factors. Together these legacy effects and local livestock systems shape the current vegetation cover, plant community composition, and forage productivity patterns of Mexico’s drylands. The decisions made by local farmers are reflected in the landscape over time, and yet the consequences of management decisions of local farmers often have unintended consequences on landscapes (Perramond 2010). The introduction of exotic forage grasses may trigger unexpected new disturbance regimes like aggressive fire cycles, instead of increasing forage quality. While private and communal cattle ranchers are transforming the biophysical landscape of arid and semiarid rangelands in Mexico, the above-mentioned government programs driven transformation of both landscape multifunctionality and local communities.
In light of these complex interactions and feedbacks among political, economic, social and governance factors, some local farmer communities have adopted adaptive livestock management practices both as an alternative to (non-functioning) government programs and in response to the opportunities provided by the spatio-temporal heterogeneity of local rangeland landscapes. These local adaptation strategies draw from intergenerational local knowledge and communal social organization. In the Altiplano rangelands of SW San Luis Potosí, several ejidos divide their land into communal rangelands and one so-called “pasta” paddock, with year-round continuous grazing in the former and short-term seasonal communal grazing in these large fenced off areas during long dry periods or droughts, in the latter. This periodic seasonal grazing increased soil organic carbon stocks, basal grass cover, the landscape functional organization index (Tongway 1995) compared to the soils of communal rangelands. Hence, local social organization and bottom-up governance enhanced the multifunctionality in these formerly highly degraded rangelands and promoted livelihood resilience. Other collaborative efforts between ejidos, government agencies and academia have permitted the examination of the long-term resilience and resistance of different livestock grazing practices on the semi-arid grassland communities measured by the multifunctionality of rangeland socio-ecological systems (Concostrina et al., 2014). These kinds of studies merge diverse knowledge systems and are based on trust and mutual interest in study outcomes.

Rangeland social-ecological systems generate win-win opportunities for sustainable development

Rangeland socio-ecological systems have evolved with the demands of local inhabitants according to their needs and interests and the historical consequences of their choices (Perramond 2010). Hence, it is the idiosyncratic nature of ejido development that ultimately feeds back and adds to the biophysical and social cultural diversity and heterogeneity, and magnifies the uncertainty with respect to landscape multifunctionality.

To tackle these complex challenges and in response to the accumulated global environmental change impacts associated with climate change, biodiversity loss, and land degradation several Mexican academic institutions founded together with international partners the International Network for Dryland Sustainability (Red Internacional para la Sostenibilidad de Zonas Áridas, RISZA) (Huber-Sannwald et al., 2020). RISZA supports the generation of multisectoral partnerships associated with local social-ecological dryland systems (Martínez Tagüeña et al., 2020). As such, RISZA facilitates intercultural exchange and dialogue, weaves together different knowledge systems, encourages transdisciplinary participatory research for the co-production of relevant knowledge for action research (Coppock 2020), and stimulates the co-design of novel governance schemes (Lucatello and Huber-Sannwald 2020). Through these approaches, RISZA ains to inform sustainable policy and socio-economic development standards in accordance with the United Nations Sustainable Development Goals (Agenda 2030).

Novel participatory research in rangeland socio-ecological settings, promoted by multisectoral partnerships that highlight the importance of diverse complementary knowledge systems associated with particular local socio-ecological rangeland systems, can lead to co-adaptive win-win management practices and thereby enhance local food security, pastoralist livelihoods, and rural sustainability. These efforts need rigorous multi-modal monitoring and assessment of both the co-production process and the social, economic, institutional and environmental outcomes so that we can learn how to implement them effectively and when they do and do not work.

Acknowledgements

We greatly acknowledge inspiring discussions held during multi-stakeholder workshops organized by RISZA between 2017-2020 with and the members of the RISZA academic technical committee. We thank CONACYT for funding the research projects PDCPN-2017-5036, SEP-CB-2015-01-251388, and FORDECYT 296354.
References


Martínez Peña, M., E. Huber-Sannwald, J.T. Arredondo-Moreno, María Cecilia Costero Garbarino y Francisco Peña de Paz. 2012. Análisis del concepto de sostenibilidad en la legislación mexicana usando el paradigma de desarrollo de las zonas secas. Interciencia 37:107-113


Mongolian herders’ evaluation of rangeland ecosystems services, values, and changes over the past decade

Ulambayar, T1, Yunden, B2, Davaasuren, N1, Balt, S1, Davaajav, D4, Zambuu, B4

1Saruul Khuduu Environmental Research & Consulting, Ulaanbaatar, Mongolia; 2The Nature Conservancy, Ulaanbaatar, Mongolia; 3The National University, Ulaanbaatar, Mongolia; 4Khovd State University, Khovd, Mongolia

Key words: rangeland marginalization; ecosystem services values; herders’ perceptions

Abstract
Mongolia’s rangeland is one of the largest remaining contiguous ecosystems encompassing 2.6% of the global grasslands, and almost three-quarters of the country’s territory, provides essential ecosystem services (ESS) for over 3 million Mongolians and 71 million livestock. The well-being of 171,605 pastoral households directly depends on the rangelands receiving provisional services in the forms of nutrition, material use and energy, regulatory services, and cultural services. This study explored herders’ perceptions of these ESS, their evaluation for ESS values, and observations of ESS change for the last decade. The study found that Mongolian herders have more benefits from provisional ESS (on average, 10 out of 18 identified), including nutritional and material use (four out of six and nine respectively), and energy services (two types out of three). An average herder household said to receive eight types of regulatory services out of 10, including environment regulation, storage/sequestration, erosion control, disease, and pest control, flood and wind protection, water cycle, soil formation and climate regulation, and six cultural services out of seven such as experiential and intellectual interactions with nature, historical and cultural heritage, both symbolic and religious-spiritual customs and nomadic identity and pride. The herders most valued the provisioning services, followed by regulatory services, and reported a “declining trend in provisioning ESS for the past decade, while, in their views, non-provisioning services remained “the same.” Herders’ reported about the exploitation of local ecosystems by external companies without sharing benefits with pastoral communities and contributing to the ESS restoration and maintenance, which was the expression of the common rangeland marginalization narrative. The study recommends necessary policies and actions to ensure equitable benefit distribution derived from rangelands to support adaptive capacity and well-being of pastoral communities, essentially acknowledge the importance of non-provisional ESS across various levels.

Introduction
Rangeland ecosystem occupies 71% of Mongolia’s 1,564,112 km² territory, supporting the livelihood of 285,482 herders and providing forage to 71 million animal in national herds (NSO, 2019). The rangeland ecosystem provides habitat for Mongolia’s iconic wildlife, including large herbivores such as the Mongolian gazelle, saiga antelope, wild Bactrian camel, Asiatic wild ass, and birds such as the white-naped crane, bearded vulture and saker falcon, and carnivores like snow leopard, grey wolves, and the Gobi bear. Rangeland vegetation varies across ecological zones, including alpine tundra (3.0% of total area), mountain taiga (4.1%), mountain steppe (25.1%), steppe (26.1%), desert steppe (27.2%), and desert (14.5%) (Hilbig, 1995). These fragile ecosystems also support expanding cultural tourism sector, a volatile cashmere industry, and a rapidly growing mining economy. Livestock herding contributes 89% of the total agricultural production, which constitutes 11% of Mongolia’s GDP, 8% of export, and employs 25% of the entire labour (NSO, 2019).

A recent 4.1% decline in rural poverty with increased income and consumption growth (NSO, 2020) might be at the expense of degrading rangeland ecosystems by overgrazing and expanding other land uses. The national statistics showed that between 2007 and 2017, rangeland area has shrunk by 124,750 ha (1% decline) being converted to other land uses, notably, urban areas (65%), mining (160%), and roads and...
infrastructure (29%) (NSO, 2019). The national rangeland health assessment conducted in 2016 found that 42% of rangelands was in a non-degraded state, while 34.6% slightly or moderately degraded, and 23.1% severely or totally degraded (NAMEM, 2018). Briske (2021) contends that a severe consequence of a rangeland marginalization narrative among policies and development programs is the undervaluation of rangeland ecosystem services (ESS), particularly regulatory and cultural services, eventually leading to the expansion of alternative land uses. He further emphasized a need for providing sufficient societal payment for non-provisioning services to balance with overly demanded provisioning services that contribute to a decline in the ecological capacity of rangeland systems (Briske, 2021). In the context of the marginalization narrative, this study explored how herders whose livelihood and identity depend on rangelands perceive the benefits and values of rangeland ecosystems and how they evaluate changes in the ecosystems’ condition for the decade of 2007-2017.

Study Site and Methods

The study sites are located in three ecological zones, including desert steppe, steppe, and mountain forest-steppe in the three districts (Chandmani, Darvi, Zereg) in western Khovd province, Delgerkhaan district of Khentii in the east, and Bayanzurkh district of Khovsgul in northern Mongolia. We randomly sampled 334 herder households out of 1708 families residing in the five study districts and defined each district’s sample size as proportional to the population (Table 1).

<table>
<thead>
<tr>
<th>District</th>
<th>Household survey</th>
<th>FG</th>
<th>Ecological zone</th>
<th>Province</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Darvi</td>
<td>58</td>
<td>2</td>
<td>Desert steppe</td>
<td>Khovd</td>
</tr>
<tr>
<td>2 Chandmani</td>
<td>38</td>
<td>2</td>
<td>Desert steppe</td>
<td>Khovd</td>
</tr>
<tr>
<td>3 Zereg</td>
<td>51</td>
<td>2</td>
<td>Desert steppe</td>
<td>Khovd</td>
</tr>
<tr>
<td>4 Bayanzurkh</td>
<td>132</td>
<td>3</td>
<td>Mountain forest-steppe</td>
<td>Khuvsgul</td>
</tr>
<tr>
<td>5 Delgerkhaan</td>
<td>55</td>
<td>2</td>
<td>Steppe</td>
<td>Khentii</td>
</tr>
<tr>
<td>TOTAL</td>
<td>334</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We used two types of survey instruments for data collection, including household surveys and focus groups (FG). The household survey was a quantitative tool guided by the International Forestry Resources and Institutions approach (IFRI, 2013) and included household demography and perceptions of rangeland and natural resource management, ESS, and household livelihood. The survey design for identifying herders’ perceptions of ESS was informed by the Millennium Ecosystem Assessment, which laid the conceptual framework and methods for measuring ESS changes (MEA, 2005). FG discussions in each district gathered qualitative information at the community level, such as important resource management stakeholders, location and current status of key natural resources, and perceived well-being categories and livelihood assessment by these classes. For survey data analysis, we used MS Excel and SPSS 23 to compare perceptions on ESS by types. The study team pre-designed an FG outline, organized them using participatory tools, and analysed audio and written records. The main findings from FG were used to complement the quantitative data analysis results.

Results

The study examined ESS types that herders benefit from, their evaluation of service values for household well-being, and perceived ESS changes for the last decade. We describe their responses by ESS categories in following subsections.

Provisioning services

The provisioning services had 18 questions about the herder access to these services that were divided in three subgroups, including nutritional benefits, material use benefits, and energy supply services. Nutrition provision included food benefits from plants, wildlife, and surface and groundwater, while the material provision had uses of wood, plants, and water for household production, livestock forage, medicine, washing, cleaning and drink for livestock, and irrigation. Energy services had three types of plant-based (wood and straws) and animal-based (dung, fat) energy sources and mechanical energy of animal power (horse, camel yak, etc.).
1) Benefits: out of 18 provisioning services identified, herder households accessed, on average, ten services ($M=9.8$), where the mean for nutrition services was 3.5 out of 6, material benefits, – 4.1 out of 9, and energy services – 2.2 out of 3 energy types (Table 2). The most common services received by the majority of herders included the use of plants as livestock forage to benefit from meat and dairy products ($N=329$), water for human consumption ($N=325$), and household water use for washing and cleaning ($N=316$). 2) Values: among the three provisional services, the most valued benefit was energy provision ($M=1.9$) compared to nutrition ($M=1.6$) and material use ($M=1.3$) that was least valued. 3) Trends: the dominant view of herders was that the provisioning services are “declining” ($M=0.98$). No one reported increasing trend in ecosystem services in their areas. The mean for the material uses benefits from ESS was lower than means for nutrition and energy services ($M=1.03$ and 1.39 respectively).

### Table 2: Herders’ perceptions on ESS benefits, values and trends by types

<table>
<thead>
<tr>
<th>Ecosystem services</th>
<th>Mean: benefit</th>
<th>SD</th>
<th>Mean: value1</th>
<th>SD</th>
<th>Mean: trend2</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisional services (18 types)</td>
<td>9.85</td>
<td>2.62</td>
<td>1.50</td>
<td>.45</td>
<td>.98</td>
<td>.38</td>
</tr>
<tr>
<td>Nutritional (6 types)</td>
<td>3.54</td>
<td>.91</td>
<td>1.62</td>
<td>.44</td>
<td>1.03</td>
<td>.38</td>
</tr>
<tr>
<td>Material (9 types)</td>
<td>4.10</td>
<td>1.58</td>
<td>1.27</td>
<td>.54</td>
<td>.82</td>
<td>.43</td>
</tr>
<tr>
<td>Energy (3 types)</td>
<td>2.23</td>
<td>.79</td>
<td>1.93</td>
<td>.79</td>
<td>1.39</td>
<td>.61</td>
</tr>
<tr>
<td>Regulatory services (10 types)</td>
<td>7.70</td>
<td>3.35</td>
<td>1.97</td>
<td>.98</td>
<td>1.48</td>
<td>.73</td>
</tr>
<tr>
<td>Cultural services (7 types)</td>
<td>5.62</td>
<td>1.93</td>
<td>2.19</td>
<td>.86</td>
<td>1.72</td>
<td>.67</td>
</tr>
</tbody>
</table>

1Values were measured at the following scale: 3=most valued, 2=valued, 1=least valued. 2Trends were measured at the following scale: 3=increasing, 2=the same, 1=declining.

### Regulatory services

The study had ten questions measuring regulatory ESS including environmental regulation, storage/sequestration, erosion control, disease and pest control, flood and wind protection, water cycle, soil formation and climate regulation. 1) Benefits: herders acknowledged their access to eight out of ten regulatory services in their areas ($M=7.7$). 2) Values: the average score for perceived values of regulatory ESS was medium or “valued” ($M=1.97$). 3) Trends: The mean for trends in regulatory services for the last ten years was 1.48, which rounded up to 2 or “the same”. This was more positive evaluation than the ones given to trends in provisioning services, which was “declining”.

### Cultural services

The survey had seven questions related to cultural ecosystem services, which included experiential and intellectual interactions with nature, values related to historic and cultural heritage, entertainment, both symbolic and religious spiritual values and values of nomadic identity and pride.

1) Benefits: on average, households received six types of cultural services out of 7 ($M=5.62$). Most frequently benefitted services were spiritual religious services where people worship mountains, ovoos (worship hills), trees (92%), and the ones related to people’s identity and pride of their places (95%), and experiential interactions including horse riding, viewing and walking in the nature (85%). 2) Values: on average, herders “valued” cultural services of ecosystem services ($M=2.19$), which was a neutral response. 3) Trends: the average score of 1.72 means that the state for the services was the same as they were ten years ago.

### Specifics of ecosystem benefits across ecological zones

Most herders from the desert steppe reported that main ESS benefits come from rangelands and groundwater resources, except Zereg which has wild onion and sea buckthorn plantations. Herders identified overgrazing, increased non-palatable plants, and desertification trends as main threads for maintaining local ecosystem services. Darvi herders criticized air pollution caused by a Chinese coal mining company, contaminating surrounding grazing areas and causing respiratory sickness for livestock. They complained that the corrupt local authorities do not take necessary measures for addressing the pollution or report on the company’s contribution to the local economy. Herders from the mountain forest-steppe receive more diverse benefits besides pastures and water, including timber and non-timber products such as wild onion, fuelwood, nuts, berries, and medicinal plants. Here grazing is limited due to large areas of forests and rocks.

The herders reported that locals and outsiders’ illegal hunting and fishing considerably reduced wildlife and fish for the past decade. According
to herders, an international flyfishing company operates in their area. Still, local communities lack neither information about business income from the local ESS nor the company’s contribution to the environment budget. In the steppe zone, the main ESS benefits come from rangeland and water use and hot springs and muds with medicinal attributes. About 15,000 tourists and 5,000-6,000 vehicles annually come to the Avarga toson lake resort for medical treatment. Although the collection of fees from the tourism businesses was sufficient, the profit usually goes to the national budget; thus, little or no income remains for the restoration of the surrounding ecosystem and environmental management. Locals reported that the Ministry of Environment and Tourism annually issues hunting permits for Argali sheep charging a hunting fee of 18-20 million MNT, but the district receives a tiny portion. The Focus groups also identified the herder perception of the good life. For most of them, the “good life” concept included the well-being of humans, livestock and nature existing in harmony. Mainly, abundant nature, health, and education of herders and happy livestock were the frequent expressions of the herders’ good life.

Discussion
The results confirmed that herders valued most the provisioning services over regulatory and cultural ESS. The provisioning services herders received most included using plants for livestock forage to benefit from meat and dairy products, water use for human consumption, and household water use for washing and cleaning. Herders had more benefits from material use among provisioning services, followed by nutrition benefits and energy use. These results were not surprising as all livestock products, including skin, wool, cashmere, etc. were under the material benefit subtype. However, herders valued more energy benefits of ESS compared to nutritional and material use benefits. This implies that strategies should prioritize supplying herders’ energy needs to address the overuse of fuelwoods.

The lack of herders’ awareness of regulatory and cultural ESS revealed during the interviews, indicates the need for raising awareness about these ESS types, and links between ecosystem functions, services, and goods with human well-being (Haines-Young & Potschin, 2010). Nevertheless, after explanation, herders’ second most valued services were regulatory services, as they seem to understand well the importance of these natural processes. Herders rated the trend in provisioning ESS as “declining”, and “the same” - for regulatory and cultural services as compared to the ESS state a decade ago which were in line with other scientific studies measuring long-term changes in rangelands (Jamsranjav et al., 2018). This finding may also imply that rural people continuously receive benefits from natural processes and spiritual and recreational experiences in their areas, although the benefits from products of provisional services are in decline. Overall, the emphasis on provisioning ESS and the lack of herder awareness of regulatory and cultural ESS may reflect the broader government policies and practices that undervalue the significance of non-provisional ESS (Briske, 2021).

On the other hand, as reported by herders, rangeland ESS benefits harvested by external agents such as coal mining, flyfishing and hunting businesses and health resorts do not contribute to the restoration and maintenance of the local ecosystems nor shared with pastoral communities. This fact confirms the narrative of ecological marginalization when more powerful actors overexploit the natural resources exposing local indigenous communities to the risk of losing their livelihood basis (Davies, 2015). Therefore, current policies need to have necessary actions to ensure equitable benefit distribution derived from rangelands to support adaptive capacity and well-being of pastoral communities, essentially acknowledge the importance of non-provisional ESS across various levels.

Acknowledgements
The study team sincerely thanks The Nature Conservancy (TNC) Mongolia for the financial support to this research, specifically, Mrs. Enkhtuya. O, Mongolia Program Director, and Dr. Bayarjargal, Science Director.

References


MEA. (2005). Ecosystems and Human Well-being: Synthesis J. Sarukhán & A. Whyte (Eds.),

NAMEM. (2018). National report on the rangeland health of Mongolia

Ministry of Environment, Green Development and Tourism, Mongolia.


Conceptualizing Pastoral Development Based on Carbon Sequestration: The Case of Yabelo District in the Southern Ethiopian Rangelands

Coppock, D. L.
Professor Emeritus, Department of Environment & Society, Quinney College of Natural Resources, Utah State University, UMC 5215 Old Main Hill, Logan, UT USA 84322-5215; Layne.Coppock@usu.edu

Key words: Borana Plateau; Ecosystem Service Payments; Social-Ecological Systems

Abstract
Major challenges for rangeland stewardship in the developing world include how to mitigate the spread of pastoral poverty and environmental degradation. Arresting such trends requires a scale of investment, policy incentives, and institutional commitments not previously observed in pastoral development. Indeed, such a rangeland revolution requires several global events to set the stage, namely: (1) Creation of markets for diverse ecosystem services; (2) recognition that improved rangeland stewardship is vital to mitigate climate change; and (3) distribution of green climate funds in support of local projects. New approaches for pastoral development projects are also needed. Previous projects have largely focused on attempts to stimulate commercial livestock offtake, but such efforts often fail. What are the alternatives? Payments to local stakeholders in support of conservation and enhanced ecosystem services such as carbon sequestration may provide one answer, shifting the development debate from livestock (provisioning services) to resource conservation (regulatory and supporting services). Yabelo District on the Borana Plateau of southern Ethiopia provides a basis for a conceptual analysis of such a shift because it has been well-described by diverse data sets. Initial results from a synthesis of ecological and economic information suggests that efforts to promote landscape change via bush control and deferred livestock grazing could increase carbon sequestration by 18% over 10 years, and thus generate annual stipends up to US $731 per capita for a population around 103,000. This poverty-mitigating action would require a global carbon price of USD $106 per ton; similar income goals could be achieved at a carbon price of USD $53 per ton if the population eligible for payment was cut in half. Annual fluctuation in carbon prices, unreliability of local markets for food purchases, up-front costs for preparatory land management at USD $1.2 M/year, and need for resource monitoring/compliance are major project challenges.

Introduction
Drylands occupy 41% of the global land area and support over 2 billion people (Safriel et al., 2015). In the developing world dryland inhabitants endure poverty and degraded landscapes. Briske et al., (2020) noted that stewardship must now tackle both human and ecological problems. Drivers of dryland change include globalization, climate change, and population growth (Briske et al., 2020).

Briske(this volume) contends that a comprehensive analytical framework and stronger organizational alliances are needed to better deal with emerging dryland challenges. Briske contends that a major reason dryland development lags behind that for other biomes is the legacy of the “drylands syndrome” (Reynolds et al., 2007) where dryland socioeconomic marginalization is emphasized. Briske notes that if global drylands are credited with a broader array of ecosystem services beyond provisioning based on livestock and small-scale agriculture, the narrative could move from marginalization to one of “global value.”

The challenge then becomes whether new pastoral development initiatives could be viable based on an economy based on regulating and supporting ecosystem services rather than livestock provisioning services. The objective of this paper is to provide such an example for a place that is well-studied; Yabelo District on the Borana Plateau in semi-arid, southern Ethiopia provides such a template (Coppock 1994, Coppock 2016). The main research questions include: (1) What could a carbon-sequestration project entail in terms of landscape management to optimize carbon sequestration? (2) under what conditions
could ecosystem service payments to stakeholders provide sufficient means to reduce poverty and promote rangeland conservation? and (3) what challenges must be overcome to make such a project concept viable?

**Study Area and Methods**

**Study Area**

The Borana Plateau is described in detail by Coppock (1994, 2016). The plateau occurs at an elevation of 1,000 to 1,500 m asl, bordered by the southern highlands to the North, Kenya (South), Rift Valley (West), and Ogaden Plains (East). The climate is semi-arid and supports a mixed savanna dominated by perennial grasses and *Acacia* woody plants. Annual rainfall averages 550-700 mm with 60% received from March to May and 30% received from September to November. Two dry seasons prevail otherwise. Multi-year droughts are frequent and climate change is making the region warmer and drier (Funk et al., 2012). The human population is on the order of 500,000 with over a million head of livestock during inter-drought periods. Massive livestock mortality occurs during droughts, but human populations endure because of food relief and other subsidies. Human emigration from the system has been restricted due to socioeconomic barriers, so local population pressure has been increasing. It is likely that more now people reside in the dozen or so urban communities across the plateau than as pastoralists living in the bush. The rural population resides in 29 *madda* (e.g., Pastoral Associations or PAs), traditional units of resource allocation including settlements, wells, ponds, and foraging zones. A declining ratio of cattle to people has characterized system dynamics for many years, contributing to food insecurity and poverty as a result of declining milk yields and asset holdings per capita. A small minority of wealthy herders own most of the livestock (Coppock et al., 2018). Livestock marketing has occurred for decades, but cattle oftake has been low. The cash economy only replaces a small portion of the traditional livestock economy (Forrest et al., 2016). Livestock development—namely creation of an effective, equitable, and ecologically sustainable system where a reliable process of animal oftake has transformed a pastoral system in positive ways—has failed here (Coppock 2016). Other systemic changes have occurred, however, including diversification of assets among the wealthy, widespread use of mobile phones, and increased interest in formal education for pastoral children (Coppock et al., 2018). The focus for this paper is Yabelo District, located in the north-central region. One of eight districts on the plateau, Yabelo District covers about 5,523 km². Statistics for Yabelo District are used for this analysis below.

**Methods and Data Sources**

Methods used in this study involve synthesis of existing information on landscape ecology, human and livestock populations, livestock production, and socioeconomic aspects of ecosystem services as relevant to Yabelo District. There is one major town (Yabelo, population est. 30,000) and seven PAs in Yabelo District.

Census data (i.e., CSA 1994, 2005, 2007, 2018) suggest a growing human population now around 147,000 with 30% urban. If we assume the urban sector, commercial crop agriculture, and a wildlife sanctuary covers 26, 20, and 2,500 km², respectively, this leaves 2,977 km² for pastoralism. With 102,900 people living as pastoralists, the overall population density in the rural area is on the order of 35/km². Other data from representative PAs in the locale suggest human population densities vary from 5 to 14/km²; PAs that have more bush-encroached landscapes have fewer people; bush encroachment has transformed the region over the past 40 years (below). Ratios of Tropical Livestock Units (TLUs) per person typically average 2.3:1 (range 1.0 to 4.0; Coppock 2016). The minimum ratio of TLUs per person for 100% pastoral sustenance is 10:1 (Coppock 1994), suggesting that only one-quarter of the total calories needed for human survival is currently provided by livestock, with the other 75% covered by food aid and other sources.

Previous research based on remote sensing for 400 km² of Yabelo District from 1973 to 2003 shows dramatic change in land cover (Mesele 2006). Grassland declined by 86%, while bushland, bushed-grassland, and cropland increased by 44, 48, and 385%, respectively. Drivers for change were overgrazing by cattle, lack of traditional control of woody encroachment using fire, and increased cultivation by pastoralists (Coppock 2016). Research has also been conducted on carbon budgets in Yabelo District (Bikila et al., 2016). They found variation in carbon stocks among three types of grassland or bushed-grassland sites: (1) Those dominated by grasses with scattered trees that have been managed for deferred grazing over 20 years (e.g., *kalo*); (2) those similar to *kalo* that have been continuously grazed; and (3) those representing former grassland sites that were overtaken by woody encroachment, and where prescribed fire was used five years prior to clear woody vegetation and reinvigorate the herbaceous layer. These site types do not match perfectly with those of Mesele (2006)—especially with respect to bushland—but there are enough similarities, as
well as insights from other studies (Birhane et al., 2017) to proceed with a preliminary analysis for Yabelo District.

There are many possible ecosystem services to select as a basis for this analysis. Carbon sequestration is the priority choice here because of the importance of carbon regulation for mitigating climate change and emerging carbon markets (Safriel et al., 2015). Reviews of carbon prices (IBRD 2019) as well as data from labor costs to implement rangeland improvements (Forrest et al., 2016) round out the approach.

Results
Baseline Statistics

Hypothetical baseline statistics for Yabelo District in 2020 are shown in Table 1. Of special note are the spatial dominance of bushed-grassland (BG) and bushland (B) sites covering 75% of the area, more people per unit area in grassland sites, fewer cattle per person in woody encroached locales due to less grass, and the highest carbon stocks per hectare in the protected Grassland-Kalo (GK). The latter occurs because carbon stocks in top soils result from improved dominance of grass cover from deferred grazing; stocks held in woody plants are less impressive (Bikila et al., 2016). The ideal scenario for rapidly enhancing carbon sequestration would be to develop more GK directly from G, and then a sequential process from BG to G and then to GK. Restoring B to GK would be the slowest of the three processes (Forrest et al., 2016).

Scenario for Project Implementation

Again, the objective is to see to what extent the local livestock economy could transition to another economy focused on carbon storage. Project implementation would need to be gradual. One activity could be to shift BG to GK at a rate of 50 km² per year. An important priority could be to simultaneously shift B to BG at a rate of 25 km² per year. It is assumed that G and C sites would remain static with no additional resource in 2020.
Cropland (C) 416 416 416
--- --- ---
All 2,977 2,977 2,977

degradation. Change in carbon stocks for BG→GK and B→BG under deferred grazing is assumed for to be stepwise over 5-year transitions. Table 2 illustrates an overall increase in GK area by 16-fold by year 10 with 12 and 44% decreases in BG and B, respectively. Carbon stocks increase by 7% after 5 years and 18% after 10 years.

Discussion

Assuming assumptions and calculations are accurate, prospects for poverty mitigation based on carbon sequestration here would be greatly influenced by global carbon prices and human population density. With a rural population of 102,900 across 2,977 km² surviving at an income level of US $2/person/day (Forrest et al., 2016), an average carbon price of USD $106 per ton could double incomes by year 10, and hence marginally mitigate poverty. A similar income objective could be met with an average carbon price of USD $53 per ton if the eligible population was reduced by half to 51,477. This could be rationalized to cover those people who are the primary managers and users of key landscapes that are altered. Given these scenarios, it would be most likely that income from carbon sequestration could only supplement livestock income (in cash and in kind). Annually variable carbon prices would add significant risk to household budgets; prices per ton used here are consistent with 2030 global targets needed to meet criteria of the Paris Accords (IBRD 2019). The analysis also illustrates the importance of sunk costs (i.e., non-recoverable investments) and time in creating viable carbon-sequestration projects to benefit pastoralists. In this model, it would take at least 5 years of considerable effort to provide a foundation for change; labor costs for bush clearing and kalo establishment (i.e., 75 km² per year at US $15,600/km²) would be around US $1.2 M per year, not including site maintenance and opportunity costs of reduced stocking rates (Forrest et al., 2016). Once a project was underway, resource monitoring systems would be needed to ensure resource use compliance. Flux in global carbon prices and unreliable local markets for food purchase add risks for pastoral households. An equitable mix of top-down and bottom-up participatory engagement among key stakeholders would be required to promote project buy-in (Coppock 2019). Other ecosystem-service provisions (i.e., water, biodiversity, etc.) could be added to the effort once the base carbon component was well-managed. Other project benefits from bush clearing, however, would include marked improvements in food security from increased livestock production (Forrest et al., 2016).

Acknowledgements

The author thanks D. Briske for spearheading this symposium. Support for the author to present this paper online at the Joint XXIV IGC and XI IRC was approved by the Dept. of Environment & Society at Utah State University.

References


et


Re-envisioning Global Rangeland Stewardship: An Ecosystem Services Assessment Framework

Briske, David D.

T.M. O’Connor & Regents Professor, Department of Ecology & Conservation Biology, TAMU 2258, Texas A&M University, College Station, Texas, USA 77843-2258; dbriske@tamu.edu

Key words: Alternative stewardship strategy, Global rangeland value; Land degradation neutrality; Rangeland marginalization

Abstract

Rangeland stewardship may be enhanced by transforming the global narrative from one of ‘resource scarcity and unpredictability’ to one of ‘global rangeland value’. This may be accomplished by devising a stewardship strategy founded on a more complete accounting of rangeland ecosystem services to inform land use planning and decision making. An ecosystem services framework may provide the necessary feedbacks to identify and assess potential tradeoffs among ecosystem services prior to implementing land use actions and policy. The ultimate goal of this alternative stewardship strategy would be to provide optimal combinations of ecosystem services to meet the needs of global citizens, while improving the well-being of millions of rangeland residents who are highly dependent upon provisioning services.

Introduction

Rangelands represent the largest land cover type on Earth and they provide diverse ecosystem services in support of humanity, including 2 billion rangeland residence (MA 2005). Yet, poverty and resource sustainability continue to represent major challenges to rangeland social-ecological systems. Even though many challenges confronting global rangelands have been recognized, an insufficient framework exists to identify and interpret these complex challenges and effectively prioritize actions and investments to address them (Dougill et al., 2012; Davies et al., 2015).

Insufficient solutions to persistent rangeland challenges may partially be a consequence of a powerful rangeland marginalization narrative. The extent to which rangelands are marginalized is inherent in the terms used to describe their limited capacity to provide forage, food and fiber; i.e., unpredictability, resource scarcity, sparse human populations, and remoteness—collectively termed the drylands syndrome (Reynolds et al., 2007). This narrative may have originated during the 19th century in western Europe based on mischaracterization of drylands as forested systems that had been degraded by pastoral exploitation, rather than a consequence of climate and environmental conditions (Davis 2016).

Institutions, policies and development programs responsible for pastoral and rangeland challenges may continue to be impeded by legacies of the marginalization narrative. For example, development programs often emphasize land improvement or recovery to a more desirable condition without necessarily referencing the desired condition. Agricultural strategies frequently emphasize the introduction of commercialized systems that optimize production to enhance food security, but emphasis on targeted short-term goals may fail to address the management of risk, uncertainty, indigenous knowledge and cultural norms (Rohde et al., 2006; Davies et al., 2015). There is growing recognition that some of these programs and policies have exacerbated the very problems they were intended to resolve, thereby increasing both resource degradation and poverty.

A critical, but underappreciated, consequence of the marginalization narrative is that the majority of rangeland ecosystem services are undervalued, either within or beyond the market economy (Sayre et al., 2013) (Figure 1). This creates conditions in which numerous ecosystem services—other than highly valued provisioning services—may become externalities during policy development and implementation because they are unrecognized or undervalued relative to alternative land uses (Dougill et al., 2012; Davies et al., 2015). The adverse impact of land privatization on wildlife
populations in African rangelands represents an example of this outcome (Niamir-Fuller et al., 2012).

Figure 1: Categories and examples of ecosystem services.

**An Alternative Stewardship Strategy**

An alternative stewardship strategy is required to replace the 20th century strategy that focused on production of select provisioning services, specifically forage and livestock production. An alternative strategy could be founded on a more complete accounting of ecosystem services provisioned by rangelands with specific emphasis on global human well-being, in addition to that of rangeland residents (Dougill et al., 2012; Reed et al., 2015). Rangelands contain 30% of the global C pool, 8 of 25 biodiversity hot spots and numerous charismatic mammals, 24% of all languages, and numerous world heritage sites (MA, 2005). This alternative strategy is founded on the premise that extensive rangeland use may represent an effective conservation mechanism. Total ecosystem services supplied by communal rangelands may be of greater total value than those of commercially managed rangelands when both monetary and non-monetary benefits are assessed (Favretto et al., 2016).

The aggregate value of regulating, supporting and cultural services associated with global rangelands may be of equal or greater value than those of the select provisioning services that are currently emphasized (Sayre et al., 2013; Sutton et al., 2016). Accelerating global drivers — human population growth, climate change and ineffectual governance — have seriously challenged the sustainability of pastoral systems, as evidenced by declining ecological and social conditions (Coppock et al., 2017). Consequently, greater demands are placed on select provisioning services, with marginal benefit to rangeland residence, while compromising the ecological capacity of rangeland systems to provision diverse ecosystem services to global citizens (Briske et al., 2020).

Therefore, the fundamental challenge facing the global rangeland community may be how to best transform rangeland social-ecological systems to provide optimal combinations of ecosystem services to meet the needs of global citizens, while improving the well-being of millions of rangeland residents highly dependent upon provisioning services (Sutton et al., 2016; Coppock et al., 2017) (Figure 2). The central challenge associated with this transition between stewardship strategies would be the complex tradeoffs that exists among individual beneficiaries of provisioning services and ecosystem capacity to provision diverse ecosystem services to benefit society (Briske et al., 2020). The ultimate objective would be to solicit sufficient societal payment for regulating, supporting and cultural services to reduce the need for provisioning services by local inhabitants, especially those with a high degree of resource dependency (Dougill et al., 2012).

Stewardship founded on the totality of ecosystem services would be strengthened by international cooperation given that rangelands exist in numerous countries and on all continents (van Kerkhoff and Szlezak 2016). For example, the Food and Agriculture Organization (FAO) recently completed a Global Forest Reassessment in which numerous global and national forest statistics were referenced to a 1990 baseline (FAO 2020). However, a specific international organization has not been designated, or has assumed, responsibility for global rangeland stewardship. Rangeland programs occur in multiple organizations, but a procedure does not appear to coordinate them, which may minimize their collective impact. Consequently, a comparable statistical assessment of global rangelands has yet to be conducted so that the extent and trajectory of global rangelands remain ill-defined (Lund 2007).

Figure 2: Inversion of ecosystem service priorities supporting 21st century rangeland stewardship.

**Creation of Missing Feedbacks**

Non-provisioning ecosystem services frequently become externalities because insufficient feedbacks exist to incorporate their full costs in economic transactions. Greater knowledge of
critical feedbacks would provide desperately needed procedures to identify and assess potential tradeoffs among ecosystem service categories prior to implementing land use actions and policy decisions (Figure 2). An assessment of potential tradeoffs would require evaluation among specific groups or bundles of ecosystem services (Reed et al., 2015). The complex logistical and ethical challenges encountered with exclusive monetary valuation of ecosystem services may be circumvented by the assignment of relative values. Deliberative monetary valuation may be an effective procedure because it is based on a combination of economic and political approaches that provides an aggregate societal value of ecosystem services (Vatn 2009). Desired proportions of ecosystem service categories could be developed for specific regions to create an ecosystem services portfolio.

An ecosystem services framework may facilitate existing programs by creating additional opportunities to assess and leverage rangeland value relative to alternative land uses. For example, land degradation neutrality (LDN) has emerged as a prominent goal for rangeland development (Chasek et al., 2019). The explicit goal of LDN is to maintain or increase the quality of land resources necessary to support ecosystem functions and services, and enhance food security. An ecosystem services framework could further support these goals by identifying baselines against which achievement is measured, and strengthen the necessary counterbalancing mechanisms. Explicit emphasis on ecosystem services may provide a common currency to enhance synergistic partnerships among the U.N. Convention to Combat Desertification, U.N Convention on Biological Diversity, U.N. Framework Convention on Climate Change, and International Union for the Conservation of Nature, as recommended in U.N. Sustainability Goal #17 – strengthen global partnerships for sustainable development (Chasek et al., 2019; Reyers and Selig 2020).

Development of an ecosystem services framework could broadly follow procedures used to create the LDN conceptual framework (Chasek et al., 2019). It consists of five modules: 1) vision and goals, 2) frame of reference, 3) counterbalancing mechanisms, 4) implementation pathway, and 5) monitoring outcomes; additional information could be derived from the target-setting procedures. Diverse representation among international organizations responsible for rangeland resources could encourage development of a robust and equitable framework and buttress the credibility of its application. The heterogeneous nature of rangelands would require development of a broad assessment framework that could be variously adapted for regional application. Alternative, novel approaches promoting integrated stakeholder engagement may prove essential for successful implementation (Coppock 2019). Institutional leadership, policies and financial resource availability, delivered as state-community partnerships, may represent essential requirements to successfully implement this transformation (van Kerkhoff and Szlezak 2016).

Implications
The transition from a stewardship strategy that emphasizes primarily provisioning services to one that accounts for the full array of ecosystem services represents a difficult, but necessary challenge. It is imperative that an ecosystem services assessment framework emphasizing the benefits of rangelands to global citizens provide sufficient societal compensation to partially offset the need for provisioning services by rangeland inhabitants, especially those with a high degree of resource dependency. This framework will require governance structures that can ensure equitable wealth distribution derived from rangelands to promote adaptive capacity and human well-being in pastoral social-ecological systems. An ecosystem services framework may complement and strengthen attainment of several U.N. Sustainability Goals, including LDN, by providing an additional mechanism to quantify targets and assess outcomes. These recommendations are admittedly bold and aspirational, but necessary to recognize and promote the global value of rangelands and the diverse and vital ecosystem services they deliver to humanity.

References


CLOSING SPEECHES

CLOSING REMARKS BY DR. ELIUD KIREGER, DIRECTOR GENERAL (DG), KENYA AGRICULTURAL RESEARCH ORGANIZATION (KALRO), NAIROBI, KENYA

The CS, Ministry of Agriculture, Livestock, Fisheries and Cooperatives
The PS State Department of Crop production and Agricultural Research
The PS State Department of Livestock
The Chairperson International Grassland Congress Continuing Committee
The President of International Rangeland Congress Continuing Committee
Distinguished Delegates

Ladies and Gentlemen

Livestock and human population is rising in the rangeland as frequent droughts and floods are causing death of livestock and human lives in many tropical regions. Increasing productivity in these regions in order to sustain these populations, is to be done while at the same time reducing degradation. In order to effectively contribute to the growth of the agriculture sector, KALRO (established through Kenya Agricultural and Livestock Research (KALR) Act 2013) works in the rangeland and grassland to develop technologies, innovations and management practices that aims to increase productivity and reduce degradation.

Ladies and Gentlemen

The rising livestock populations, increased settlement and degradation has affected the livestock feed security, mainly grass and forage based sources. Kenya has a long history of grassland/rangeland research and development in East Africa, dating back to early 19th Century, culminating in the setting up of the Grassland Research Station in Kitale in 1950s. Many of the grass species developed in this station have found their way to other tropical countries such as Brazil and Australia where they have been greatly improved making those countries leading beef producers globally. The KALRO is now implementing a programme to repatriate some of these forages back to Kenya to boost the livestock industry.

During the launch of the African Green Revolution Forum (AGRF) of 2021 Conference, the president went ahead and declared drought as a national disaster in Kenya. In order to deal with the perennial feed shortages, KALRO has introduced, through its Arid and Rangeland Research Institute (ARLRI), a re-seeding program, where grasses, mainly indigenous and introduced, are used to improve the rangeland. The Institute has enabled farmers to produce enough grass for their livestock, stock more in form of hay and sell to other farmers. In the coastal lowlands and highlands, which are currently experiencing droughts, Brachiaria grass has been introduced. The resilient grasses sequester carbon and have an additional benefit of reducing greenhouse gases.

Ladies and Gentlemen

Today, we in KALRO have adopted the ‘Climate Smart Agriculture Strategy, 2017-2026’ in developing technologies, innovations and management practices. Technologies we develop are climate smart, in order to sustainability increase income and productivity. The theme of the Congress “Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods” therefore share KALRO’s desire to build resilience and increased agricultural productivity and improving livelihoods of the people living within the rangeland and grassland.
Ladies and Gentlemen

Ensuring food and nutrition security in the region depends not only on improved forages and animal breeds, but also on education of the communities and having vibrant seed systems. In partnership with private sector, including mass media, KALRO has repackaged knowledge from research and delivered to farmers directly on print, TV or radio media or through county extension service. In terms of providing quality forage seed KALRO works with farmers and the Kenya Plant Health Inspectorate Services (KEPHIS) to produce seed to enable farmers establish own pastures. KALRO is also a major source of superior animal breeds, for example Boran and Sahiwal bulls and superior camel breeds for the very arid rangeland.

Ladies and Gentlemen

The unpredictable weather is still a challenge and KALRO, working with Kenya Meteorological Department (KMD), has introduced ICT based advisories, which not only give weather predictions, but have components on existing markets for livestock products. Among them is the Kenya Agricultural Observatory Platform (KAOP).

Finally, KALRO has had the privilege of being part of the organizing team for the congress, and offers to participate by sharing its experiences, beliefs and approaches to tackle adverse effects of climate change the productivity of grassland and rangeland in Kenya.

Thank you
I want to start by highlighting two significant accomplishments of the IGC Continuing Committee during the last two years. As you all know, the IGC and the IRC Proceedings are a permanent record, a permanent legacy of research in grassland and rangeland. They will outlive us all. Now, not only are past Proceedings available through libraries around the world, but we have the past five Proceedings available as a searchable database. Anyone around the world can simply google an author’s name, and keywords from one of their Proceedings papers and the paper will be available for viewing or downloading. If this simple search does not work, then add International Grassland (or International Rangeland for the Joint Congresses). A record of the number of downloads will also be provided for author’s vitæs. The International Grassland Congress recently obtained copyright permission from Wageningen Academic Publishers for the XX IGC in Ireland (2005) to be included in the searchable database, previously this Proceedings could only be purchased as a hard copy or e-book. The Proceedings site has been developed by the University of Kentucky library system, hence the name UKnowledge. To reach the main site go to internationalgrassland.org under click on publications or google International Grassland Proceedings. We are working towards all the Proceedings being on this site in coming years, even translated copies of the first two Proceedings which are in German.

A comprehensive IGC history was released in early 2021 “The History of the International Grassland Congress - 1927 to 2020”. The IGC Congresses began with an invitation letter that Dr. Fredrich Falke sent to 50 grassland scientists in mainland Europe and the subsequent gathering and tour for 16 of these scientists in Germany in 1927. There are many details from these early years of IGC that we would not know without the publication of this history. The history includes information from every IGC Congress and other significant events in grassland research during the last 93 years. Many supplemental documents are also included in the appendix including short biographies of the six most influential men during the first 20 years including: Dr. Falke (Germany), Dr. Anders Elofson (Sweden), Professor Albert Volkart (Switzerland), Sir R. George Stapledon (United Kingdom), Dr. ir. Derek Siewert Huizinga (Netherlands), and Professor Richard Geith (Germany).

The history began as an idea by Dr. Garry Lacefield (USA) and myself soon after the XXIII IGC in India. We felt like an update and expansion of the IGC History by Dr. Ross Humphries in the late 1990’s was in order. Dr. Lacefield talked with Dr. Vivien Allen about working with us on the history, based on her long-term connection with IGC including serving as Chair of the Continuing Committee from 2001-2005. She also chaired the International Forage and Grazing Terminology Committee that published An International Terminology for Grazing Lands and Grazing Animals in 2011. This was a collaborative effort with both the International Grassland Congress and the International Rangeland Congress. Dr. Allen began to discuss details of the IGC history with Dr. Roger Wilkins (UK) who played a prominent role in writing the initial IGC Constitution in 1978 and the revised version in 2001. As the months passed, Drs. Allen and Wilkins became the primary authors of the history and used their many worldwide grassland contacts to source information that would have been unavailable to the average IGC member. The resulting almost 400 page book is a compelling read to anyone interested in grassland. It can be ordered from the IGC website (internationalgrassland.org) as a hard copy book or downloaded as a pdf document.

As I stand here in Kenya today, I want to say that one of the highlights of my professional career has been working with such an outstanding group of scientists, administrators, and staff at KALRO (Kenyan Agricultural & Livestock Research Organization), at the Kenyan Ministry of Agriculture, Livestock, Fisheries and Cooperatives, and other organizations in Nairobi. They have been patient with me ever since my first Congress planning visit in 2016. They have been patient as I mispronounced their names. They have been patient as I broke nearly every formal meeting protocol, often breaking in when chairs of committees had the floor. I’m sure if I was Kenyan, I would have been demoted. But they just smiled and nodded their heads and gave me the floor.

I flew into the country at least every year either on my own, or with Dana Kelly (IRC Chair), Jim O’Rourke (IRC Secretariat), and once with Derek Woodfield from the IGC Continuing Committee. We expected them to break away from their many job responsibilities for several weeks before and after our visits. And, to my knowledge, none were paid more than their regular salary. But they were expected to do more. And to a man and to a woman they rose to the occasion. Thank-you.
This Congress in Kenya all started with Dr. David Miano and his leadership as chair of the IGC Continuing Committee after the IGC Congress in Sydney, Australia in 2013. He showed vision and leadership in working with colleagues to bid for the Congress to be held in Africa for the first time. David initiated gathering together his colleagues at KALRO. He organized the team that came to the IGC Congress in India to accept the bid. He then helped spearhead the effort to develop a bid for the International Rangeland Congress and brought a delegation to Saskatoon Saskatchewan Canada in 2016 to present the bid that this be a Joint Congress. Thank-you David. It’s been an honor to succeed you.

There are many, many people I’d like to thank, on behalf of myself and Dana Kelly. We have worked with 3 Principal Secretaries of Livestock, but the longest with Harry Kimtai, chair of National Organizing Committee (the NOC) Principal Secretary State Department for Livestock. He personally led most of our 15 NOC meetings. He always made us feel welcomed each time we visited with him in his office. Thank you.

We’d like to thank the Director General of KALRO Dr Eliud Kireger, Vice Chair of the National Organizing Committee for his support of a joint Congress. I remember the first time we met in February 2016. I was very nervous as I entered his office, trying to remember the protocol I had been told to follow.

Both of these men made the extraordinary effort to accompany the Kenyan delegation to the Society of Range Management meetings in Denver CO in February 2019. They participated in the meetings and manned the Congress booth. And they joined with us as we cheered on Dr Ernest Bogo when he dressed as a Swahili warrior with a tall Gallagher fence post as a spear. I assume the airlines wouldn’t permit a real spear. Little did we know that Covid would soon devastate the world. But they stayed committed and supported the Congress during these tumultuous and unpredictable times.

We’d like to thank the government of Kenya for their tremendous financial support. Cabinet Secretary, Ministry of Agriculture, Livestock, Fisheries and Cooperatives, the Hon. Peter Munya gave his full support for the Congress.

We want to give a special thanks to Dr Joseph Mureithi, Deputy Director General (Livestock) for KALRO and the Chair of the Secretariat for the Congress. He gave much of the administrative oversight for the activities of the secretariat. Over all these years, Dr. Mureithi has provided great foresight and leadership. He also attended to many tasks large and small, even personally lining up drivers to pick us up from the airport. He is now a close friend. Thank-you Joseph. And my invitation to host you and your wife Grace in our home in Kentucky in 2023 is very genuine.

We want to thank Dr Elkana Nyambati, the secretary of the Secretariat for his key involvement with all of the Congress committees. When we would head back from Kenya after one of our week-long trips, we would both get emails from Elkana late at night as he followed up on all the tasks that we had come up with during our visits. Thank-you Elkana.

We want to give a special thank-you to Primrose (Nabwire). She was the wheel that kept everything running. From receiving and distributing proceedings papers to reviewers, to handling registrations, to recording and typing meeting minutes, to calling the PS’s office to line up meetings, and about a million things more. You may think I’m exaggerating but I’ll bet if you count all the emails that Primrose has answered during the last few years, it would add up to a million (or at least several hundred thousand).

There are so many others to thank. Especially the leadership of the Secretariat. Thank you Floridah (Maritim) for chairing the publicity committee and Stephen (Odipo) for being the secretary. You both worked long hours for this Congress, especially in the last months. Thank-you Simon (Onchiri) for chairing the local arrangements committee and Cecilia (Onyango) for being the Vice-chair. Thank-you Elkana for serving as secretary to this committee. You all worked so hard lining up the Congress venue, hotels and all the other aspects for a physical meeting, and then you had to shift gears and line up details for a virtual Congress.

Thank-you Patrick (Watete) for chairing the tour committee, Oliver (Wasonga) for serving as co-chair, and Michael Okoti for being the secretary. You spent many long hours planning and conducting reconnaissance trips for some amazing pre- and mid-Congress tours around Kenya and even to Tanzania. I know that Dana and Jim really enjoyed their reconnaissance trip south into Tanzania, and we wish we
had been able to run this for the Congress. More recently you worked with Stephen and others to develop virtual tours. Thank-you.

We want to thank Patrick (Ngicuru) for serving as chair of the finance committee and Festus (Murithi) for serving as secretary. This was a critical role you played, and you both showed diligence with the many permutations of the budget and the paperwork involved. And thank-you George (Keya) for chairing the fundraising committee and Alice for serving as secretary.

We want to give a special thank-you to Professor Moses (Nyangito) for chairing the publications committee, Dereje (Wakjira) and Lance (Robinson) for serving as co-chairs, and to Jane (Wamuongo) for serving as secretary. Lance, thanks for your commitment for working so diligently with the committee even after moving back to Canada from Kenya. You and the entire team handled 1000 abstracts and arranged for each one to be reviewed. Then you fielded over 600 full length paper submissions and had all of them reviewed and some re-reviewed. Then you worked with the program committee to make sure all of this would fit into a program.

And we want to give an extra thank-you to Professor Jesse (Njoka) for so capably chairing the program committee and An (Notenbaert) for serving as co-chair. Professor, you put in so much effort on the initiative for a Traditional Knowledge Forum. The forum may not have been held at this Congress but the groundwork that you and Dana laid sets a valuable foundation for it to be held at future Congresses. Thank-you Foustine (Wandera) for serving as secretary of the program committee. And serve you did. I know you had many late, late nights working on the 3rd, 4th, 5th, ….. 10th versions of the program. In-person, hybrid, in-person, virtual, maybe hybrid and then finally virtual. Thank-you.

Thank-you Caroline for helping in recent months and Protel for the tremendous work you did over the last few weeks and especially the last few days. We also want to thank all those that were heavily involved early on and have since retired or moved on to other positions. Thank you all.

You’ll notice I used many first names. This is not the professional protocol in Kenya, but I was very deliberate in doing this to show the close working relationship Dana and I have had with all of these individuals over the last 5 years. I’ll make sure to add last names to my written transcript that goes into the permanent proceedings, but to me I’ll always think of you fondly by your first names.

We want to thank Dr. Jim O’Rouke, permanent secretariat of the International Rangeland Congress. He has been the backbone of the IRC organization for years, going back to 1978 when he was one of those who helped start the International Rangeland Congress. He started his official duties with IRC in 1995 as a member of the continuing committee, then as President of the Continuing Committee and now as secretariat. Jim, it has been great working together all these years and I have fond memories of Dana, Stephanie and I sitting with you at the Jacarada hotel with your Tusker beer in hand and sharing stories of being a young range scientist in Tanzania and all your adventures during those years. Even driving all the way to Nairobi for groceries. And most of all Jim, thank-you for raising the majority of the outside sponsorship that allowed so many delegates to attend this virtual Congress at no charge. And I thank-you on behalf of all those attending right now because of you.

I have several more thank-you’s. A huge thank-you to Dana Kelly. Officially, Dana and I share the same position leading our Continuing Committee. She as President of the IRC Continuing Committee and me as Chair of the IGC Continuing Committee. But that’s just the surface. Dana, it has been a pleasure and a joy working with you over the last 5 years. I’ve seen you show grace and leadership, even under tremendous pressure. I’ve seen you show extreme politeness and I’ve seen you show forcefulness when necessary. I have seen you provide incredible vision for IRC over the years and leadership for initiatives like the International Year of Rangeland and Pastoralists. I have so appreciated working with you professionally, but even more knowing you as a dear friend to Stephanie and I. Thank-you Dana.

And a special thank-you to my wife Stephanie. We have been married 38 years and have 4 grown children and now 7 grandchildren. You stood by my side through grad school and 30 years of a very demanding professional career. And little did you know when we were in India and I told you I’d been nominated to chair IGC that it meant working double and triple overtime from my day job at the University of Kentucky. Thank-you Stephanie. Thank you also to Dana’s husband, Mark, as he has supported her work on the Congress over the years.
Now, speaking to all of my Kenyan colleagues and friends who are sitting in front of me (Note: the NOC secretariat met in person in Mombasa during the week of the Congress). There have been profound changes in our world during the last two years, but you have and are rising above. Covid will not defeat you or any of us, just as the IGC leadership resurrected the organization after a 12-year break during and after WWII. You have risen to confront these formidable challenges and have overcome. Sure, you are disappointed not to be hosting delegates in-person in Kenya to experience the people, the culture, the vast and beautiful grassland and rangeland. But you have given them a taste, an introduction, and reason to visit and spend time here in the future. And you have continued the legacy of both the IRC and the IGC. You have provided the platform for this Congress, the recorded presentations that are now available to all delegates and the permanent proceedings papers that will be available for generations of scientists. And although this Congress was virtual you have still helped create very real and lasting interactions between researchers from many countries. Thank-you. Asante-sana.

Lastly, Dana and I want to thank all of you around the globe. Thank-you for your perseverance and patience with the postponement of the congress, with delays, with extensions, with communication issues. Thank-you for sticking with us and helping move all of us forward toward even greater significance in our profession fields, influence on policy, and most significantly in our efforts to improve the lives of those residing on the rangeland and grassland of the world. Thank-you.
CLOSING REMARKS BY MR. HARRY KIMTAI, PRINCIPAL SECRETARY (PS), STATE DEPARTMENT OF LIVESTOCK (SDL), MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVES (MALFC), NAIROBI, KENYA.

President International Rangeland Congress Continuing Committee, Prof. Dana Kelly
Chairperson, International Grassland Congress Continuing Committee, Prof. Ray Smith
Director General, KALRO, Dr. Eliud Kireger

Distinguished Delegates

LADIES AND GENTLEMEN
The 24th International Grassland and 11th International Rangeland Joint Congress, the first-ever joint Congress to be hosted in Africa virtually, is coming to a close. This Congress was set to do three things:

i. Bring out and discuss key issues affecting global grassland and rangeland resources;

ii. Propose interventions, resolutions and guidelines on how to address food and nutrition security challenges arising from use of world grassland and rangeland production systems; and

iii. Bring to the fore the role of public and private partnerships in improving global grassland/rangeland resources and their derived livelihoods, particularly for pastoral people.

LADIES AND GENTLEMEN
This Congress was conducted through plenary concurrent sessions, and also panel discussions in order to enable scientists, practitioners and policy makers participate and contribute to the matters in their hands. We had sessions on Range/grassland ecology; forage production and utilization; livestock production system; wildlife and tourism; biodiversity, ecosystem services and ranching; incorporating education in building capacity of the pastoralists to manage rangeland/grassland; among others.

The Continuing Committees of the International Rangeland and International Grassland Congresses, entrusted Kenya to host the joint congress and we are indeed grateful. Their decision is justified by the high level of participation witnessed in the Congress and to the many very fruitful discussions that were held and the resolutions reached. I believe, if the resolutions are adopted, we shall have sustainable Range-land and Grassland where livestock, wildlife and pastoralists co-exist in complex inter-relationships that finally will give rise to economically vibrant ecosystems.

LADIES AND GENTLEMEN
Kenya and the horn of Africa is currently facing severe drought which is attributed to the effects of global climate changes. The region has keenly followed the proceedings of the Congress and is eagerly waiting to receive the formal proceedings to tease out potential lessons and solutions that can assist cope with the effects of climate change. Such lessons will also include those on improving pastoralists’ way of life and on addressing environmental degradation. Specifically, based on those lessons, national policies and strategies will be revised to sustainably develop and utilize grassland and rangeland in order to contribute to our national economy.
The Kenyan Government is more than ready to support our researchers to continually promote the interchange of scientific and technical information, create awareness on all aspects of grassland and rangeland in Kenya, working together with other countries. I want to believe that this scientific research will not only be an exchange of information between the researchers alone, but will improve sustainable utilization of the rangeland and grassland for improved livelihood and welfare of the wildlife not only in Kenya but also contribute to improvement all over the world. We therefore need to create a lot of awareness along those lines.

LADIES AND GENTLEMEN

As we draw the curtain on this year’s Congress, may I offer my gratitude first to the office of the Cabinet Secretary, Ministry of Agriculture, Livestock, Fisheries and Cooperatives under Hon. Peter Munya for its support towards the successful organization of the Congress. Secondly may I thank my colleague Prof. Hamadi Boga, PS State Department of Crops and Agricultural Research; Director General, Kenya Agricultural and Livestock Research Organization, Dr. Eliud Kireger, the President of the International Rangeland Continuing Committee, Prof. Dana Kelly and Chairman of International Grassland Congress Continuing Committee, Prof. Ray Smith.

I also wish to thank the entire membership of National Organizing Committee and the NOC Secretariat for working tirelessly to make this congress a resounding success under very challenging conditions of the global COVID 19 pandemic. I thank all those who submitted oral papers, posters, and all those who participated in plenary sessions.

Finally, I thank all the sponsors who supported this Congress. I am encouraged that as we bring this congress to a close that there is great hope for “Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods”, which was the theme of the Joint Congress. I now wish to declare this Congress officially closed.

ASANTE SANA!!!
ABOUT THE JOINT INTERNATIONAL GRASSLANDS AND RANGELANDS CONGRESS

International Grassland Congress (IGC)
Grasslands cover a very large portion of the earth’s surface and are important as a feed source for livestock, as a habitat for wildlife, environmental protection, carbon sink and for in situ conservation of plant genetic resources. In developed and developing countries, many millions of livestock farmers, ranchers and pastoralists depend on grasslands and conserved products such as hay and silage and on a range of fodder crops for their livelihoods. Grasslands also contribute significantly to cropping systems, with a large part of crop yields being dependent upon the benefits of the pastures and herbaceous legumes. The International Grassland Congress is held in every 3-5 years and promotes interchange of information on all aspects of natural and cultivated grasslands and forage crops for the benefit of mankind, including sustained development, food production and the maintenance of biodiversity. It is the major international forum for scientists involved in grassland and livestock R&D and for people managing one of the world’s largest natural resources. The International Grassland Congresses have spanned the globe in its close to 100 years’ history and have been held on every continent with the last five in Brazil, Ireland, China, Australia, and India, this one in Kenya and the upcoming in the United States in 2023.

International Rangeland Congress (IRC)
Rangelands, primarily covered by natural vegetation, provide grazing and forage for livestock and wildlife. Rangeland and grassland ecosystems provide benefits vital to agriculture and the environment including: grazing and forage for livestock and wildlife; watersheds for rural and urban uses; habitat for plants, insects, and animals; water for sustainable landscapes; areas for recreation activities; and potential renewable energy and mineral resources. The International Rangeland Congress (IRC) is held every 3-5 years and its aim of the IRC is to promote the interchange of scientific and technical information on all aspects of rangelands: research, management, extension, education, training planning, and development. The last five congresses have been held in Australia, South Africa, China, Argentina, Canada, this one in Kenya and the upcoming in Australia in 2025.

The aim of the Joint XXIV International Grasslands and XI International Rangelands Congress was to promote the interchange of scientific and technical information on all aspects of grasslands and rangelands. This Joint IGC-IRC Congress was hosted by Kenya, 25th – 29th October, 2021.

Congress secretariat: Joint XXIV IGC and XI IRC
P.O. Box 57811 - 00200, NAIROBI, Kenya,
Email: Kenya2021-igc-irc@kalro.org | kenya2021igcirc@gmail.com
info@kalro.org
Website: http://2021kenya-igc-irc.rangelandcongress.org